

Monitoring the Planet's Heartbeat:

Keeping track of the “solid” Earth

Presentation to ESS+20 Symposium

June 22-24, 2009

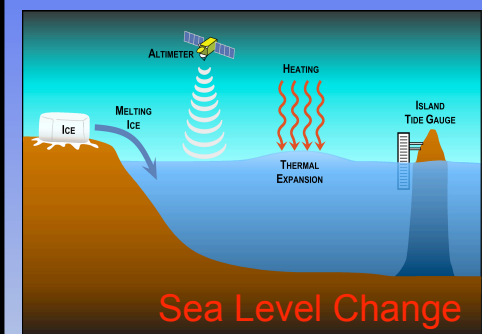
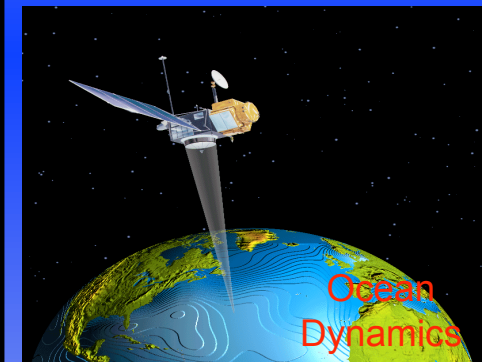
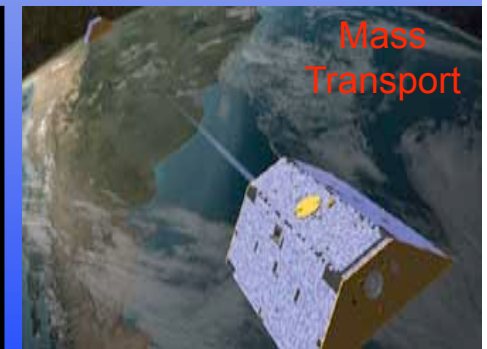
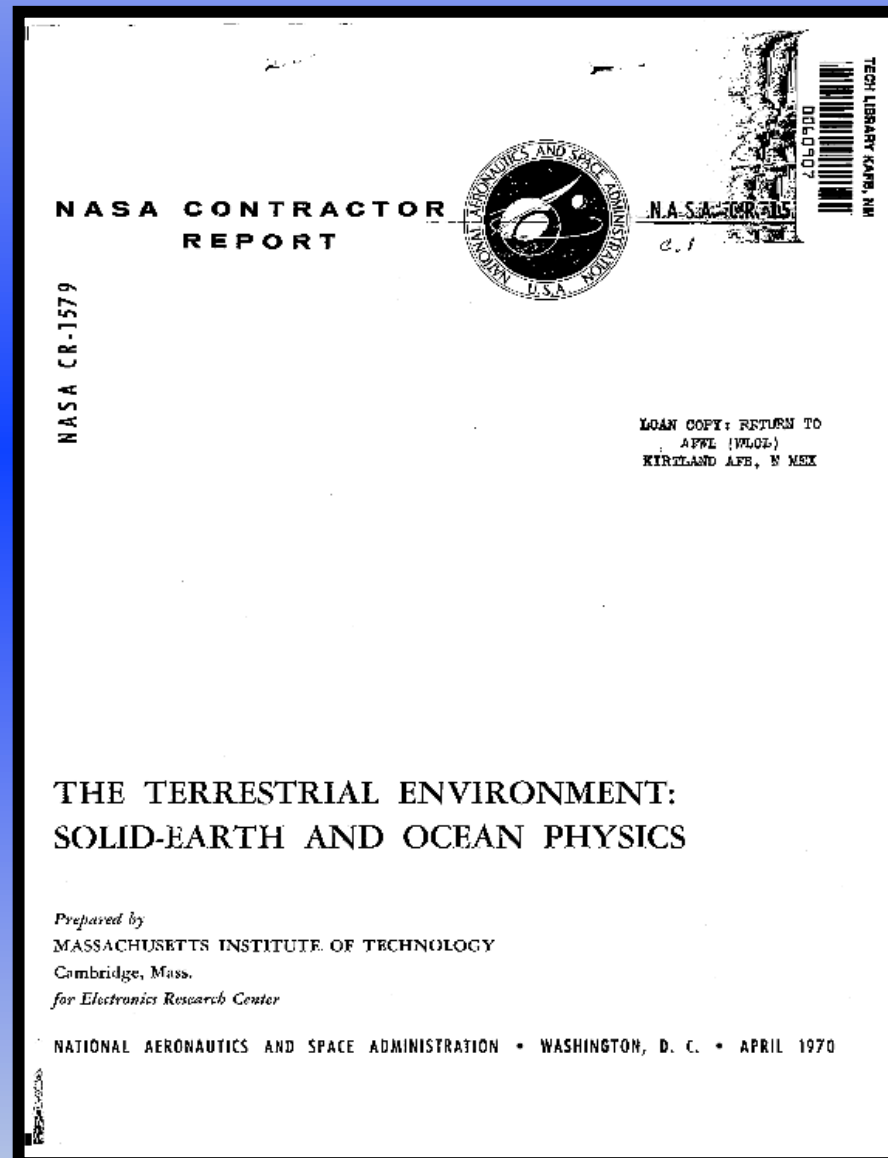
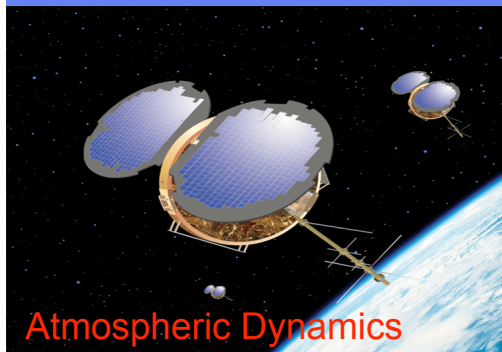
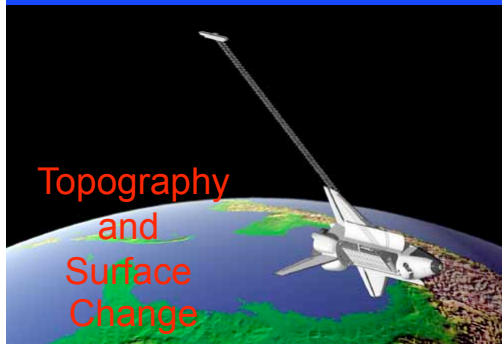
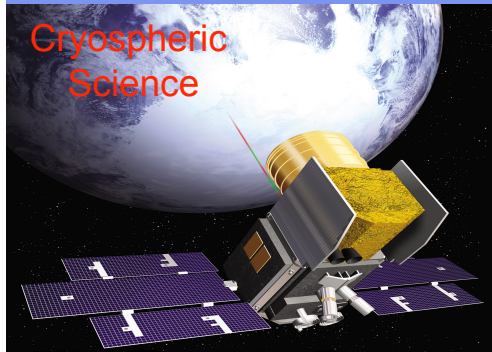
Washington, DC

Jean-Bernard Minster

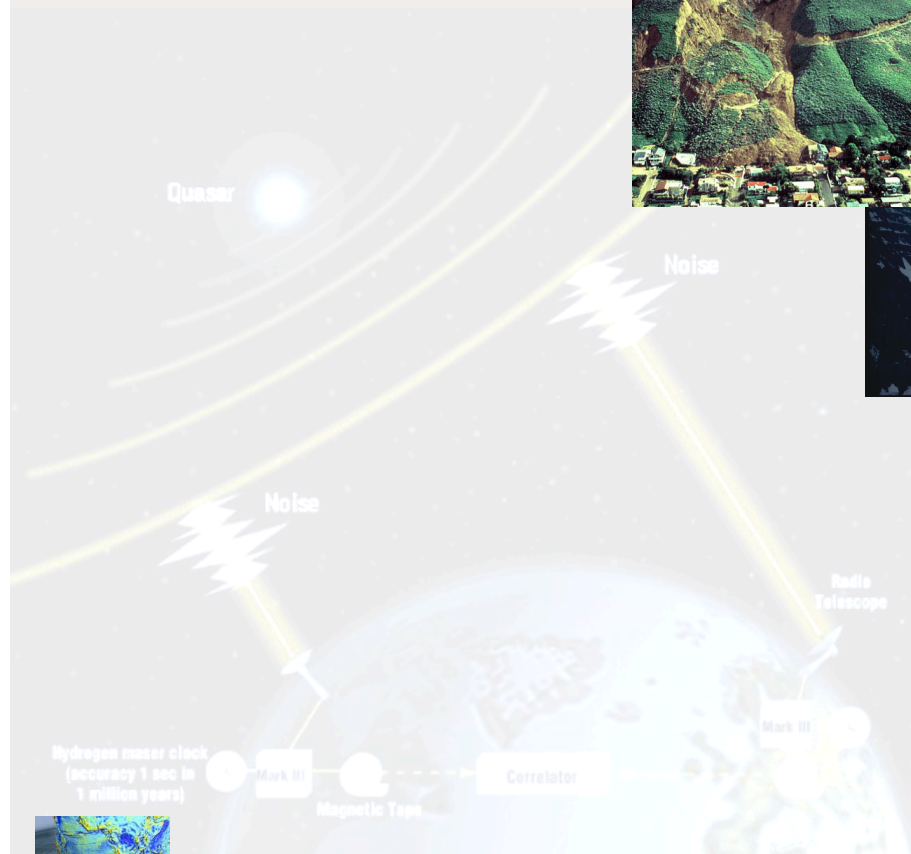
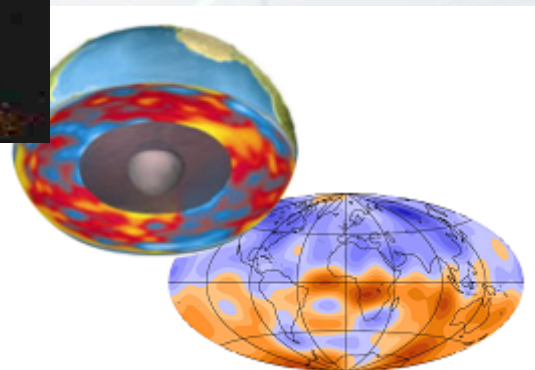
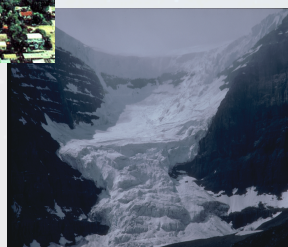
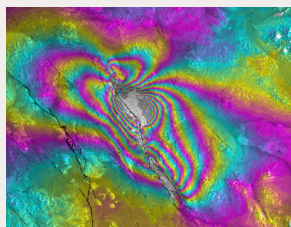
+ cast of 1,000's

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The Williamstown Report (1970) Recommended the Development of Space Geodesy for Solid Earth and Ocean Physics Applications of Space Geodesy Have Blossomed



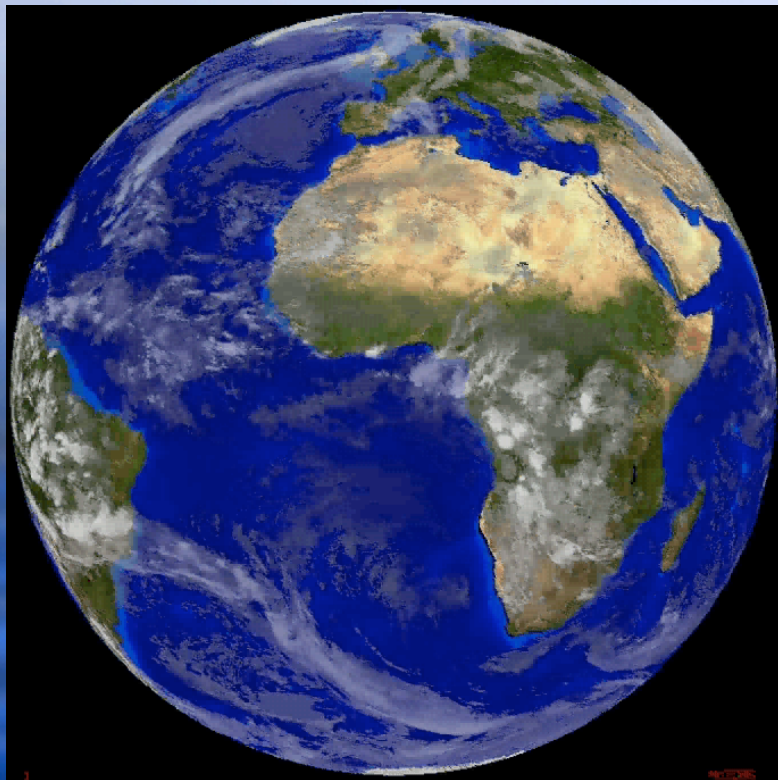
Scientific Challenges



EarthScope Provided With 30 meter High Resolution SRTM Topography



Is Space Geodesy Ready for the Decadal Study Challenge on Sea level Change?



Our Reliance upon Geodetic Networks and Reference Frames

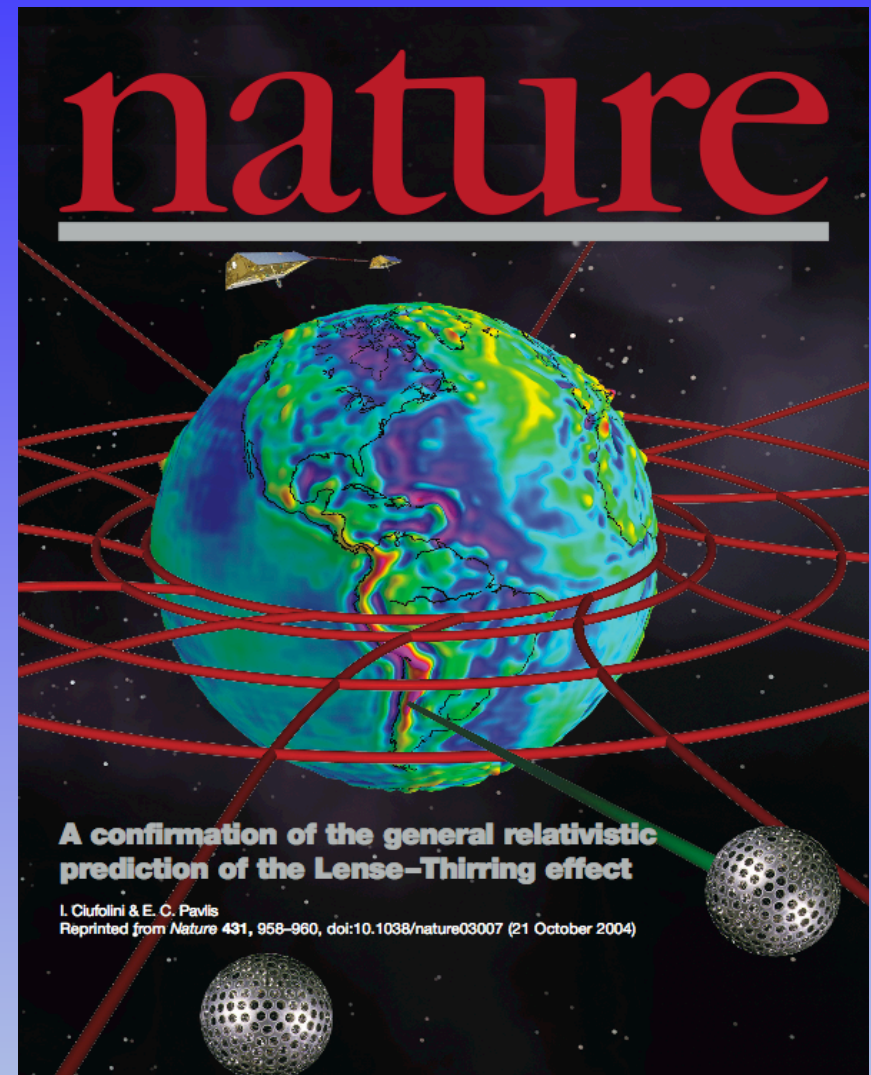
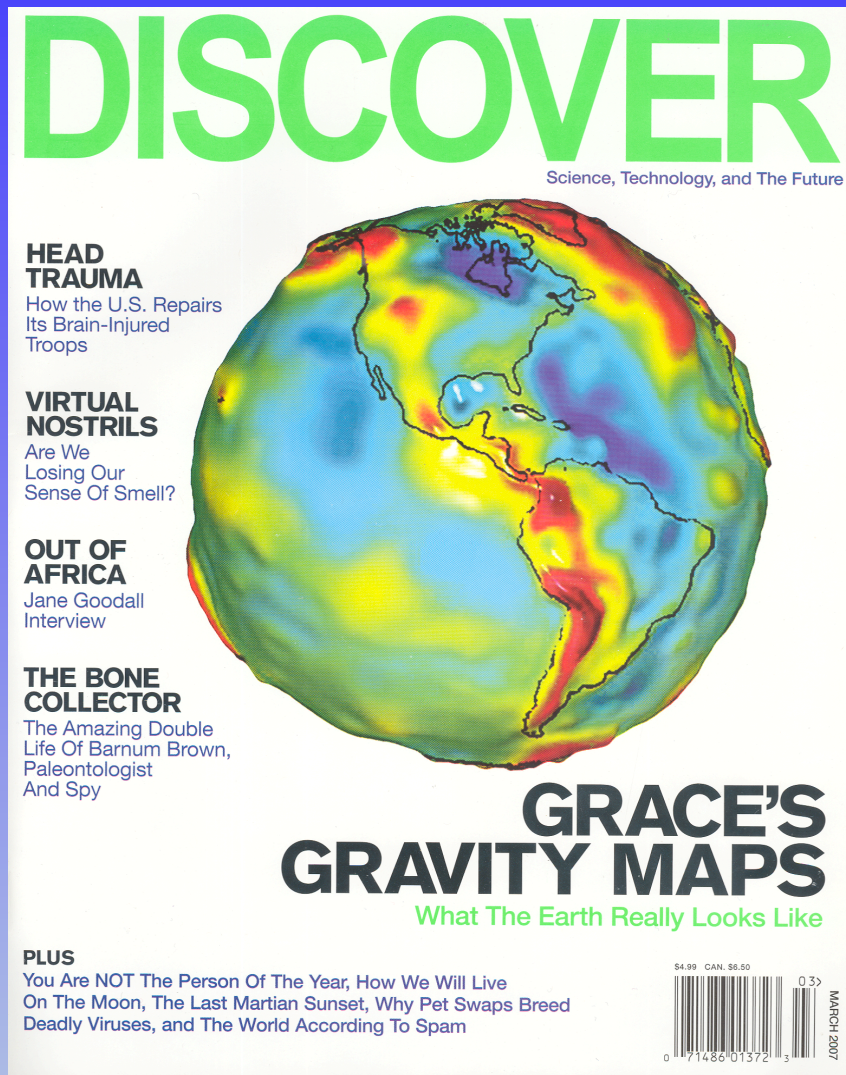
John LaBrecque

Lead, Earth Surface and Interior Focus Area
Science Mission Directorate
NASA

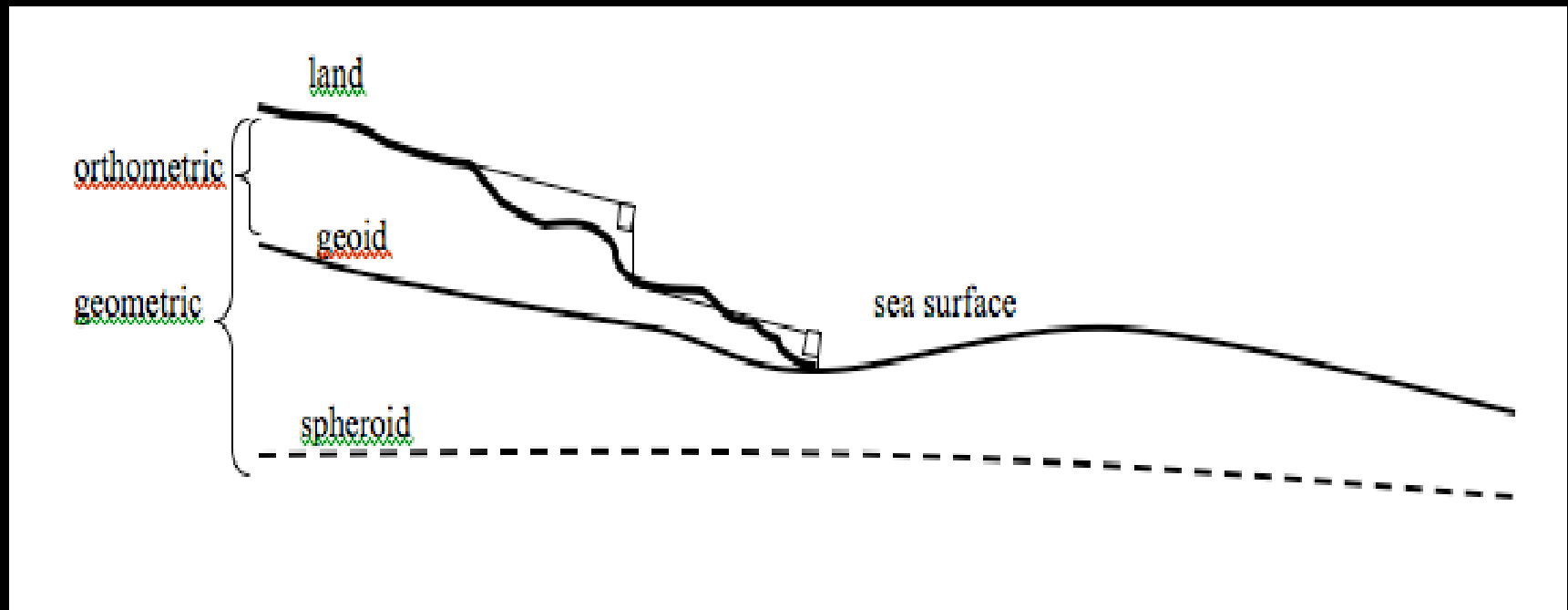
Chopo Ma, Byron Tapley, Erricos Pavlis, John
Ries, Zuheir Altamimi, Michael Pearlman

1. 1 ppb resolution equals 6.378137 mm at the Equator
2. Sea level is rising at about 3.3 mm/yr (0.52 ppb/yr)
3. Models of Sea Level Rise resolve 0.1 mm/yr (0.016 ppb/yr)
4. ITRF Accuracy at 95% Confidence is 6.4 mm (1 ppb) drifting at 3.2 mm/yr (0.5 ppb/yr)
5. ITRF Goal is 1 mm (0.2 ppb) accuracy with 0.1 mm/yr (0.02 ppb/yr) stability.

Space Geodesy is a NASA Science that Cuts a Wide and Important Swath through the Scientific Landscape

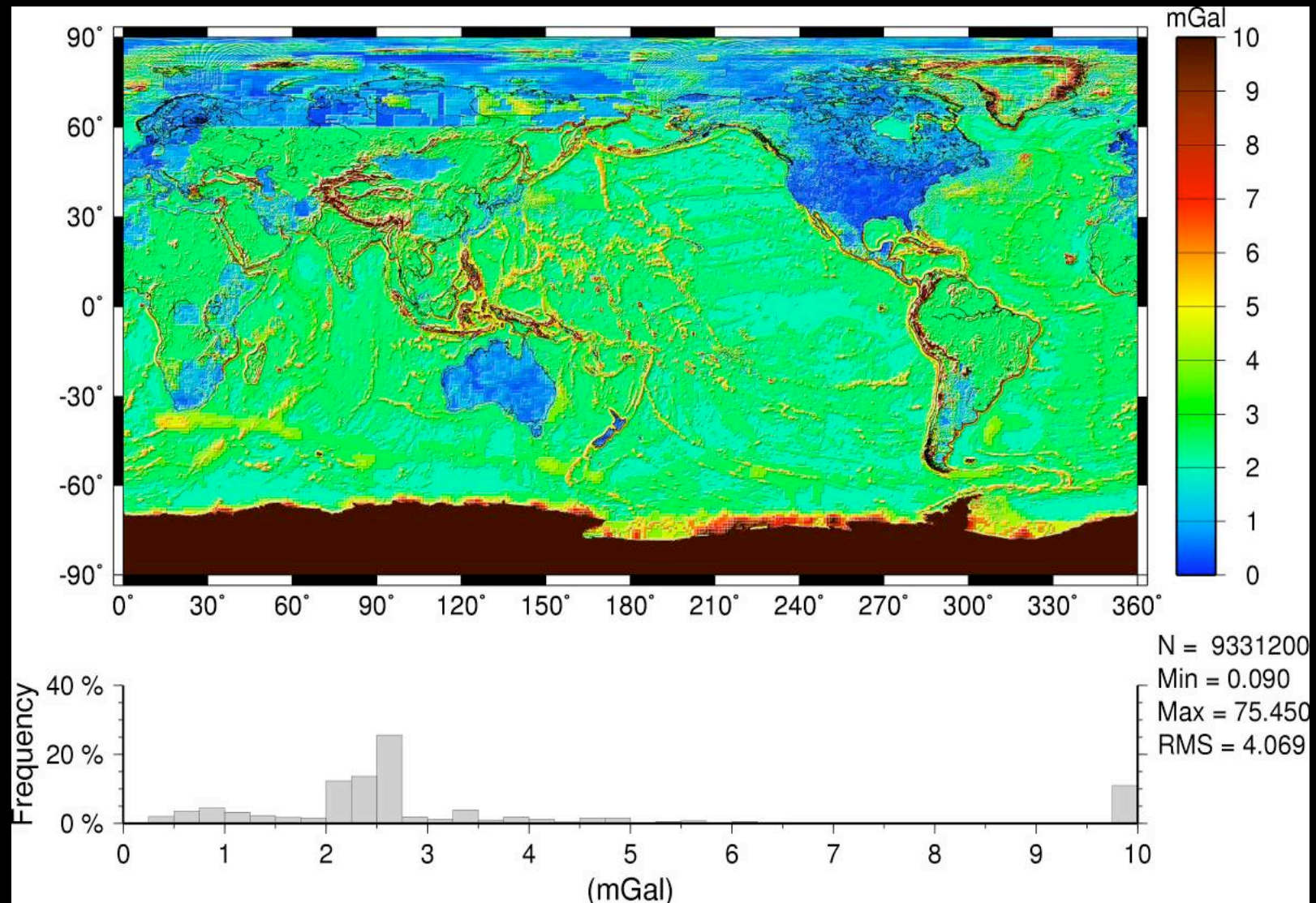


Various heights!



- but the water knows!

Gravity field errors



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Sea Level

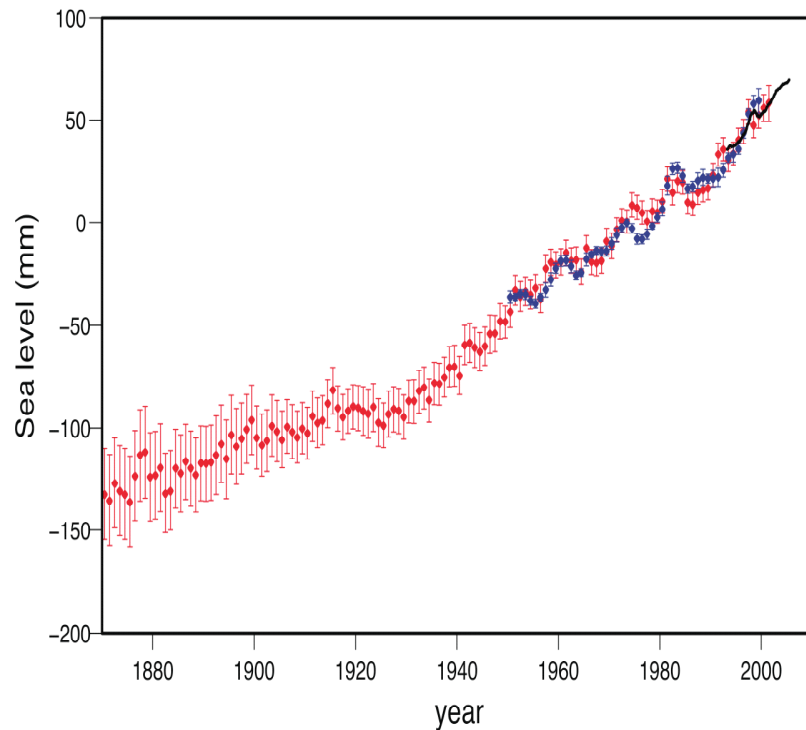
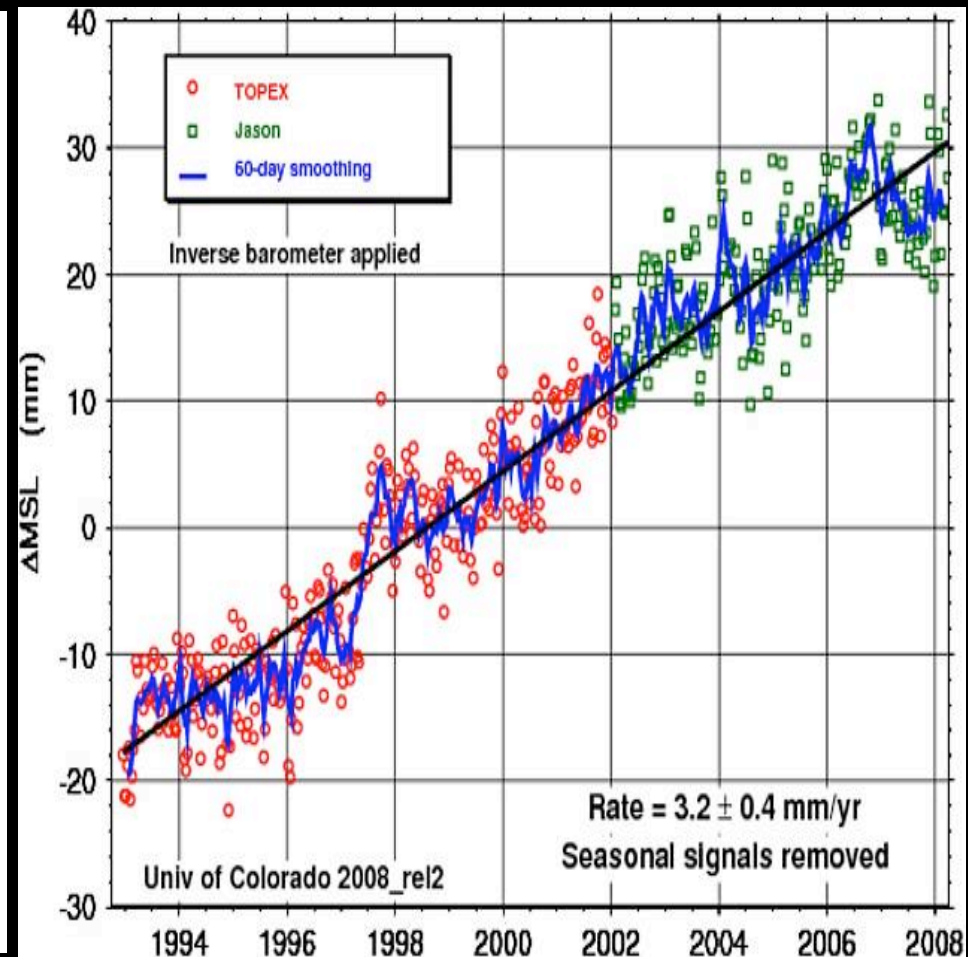
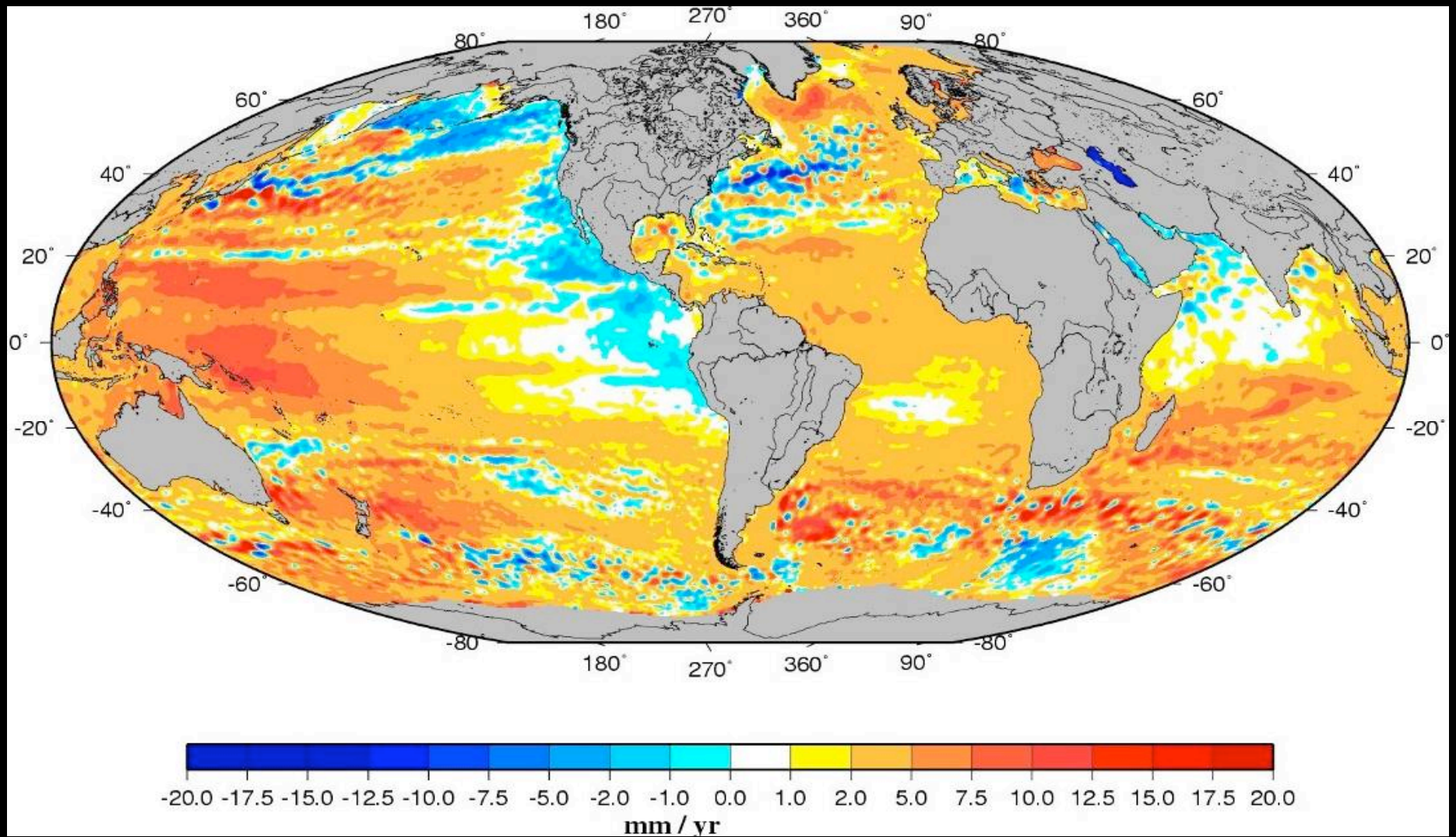


Figure 5.13

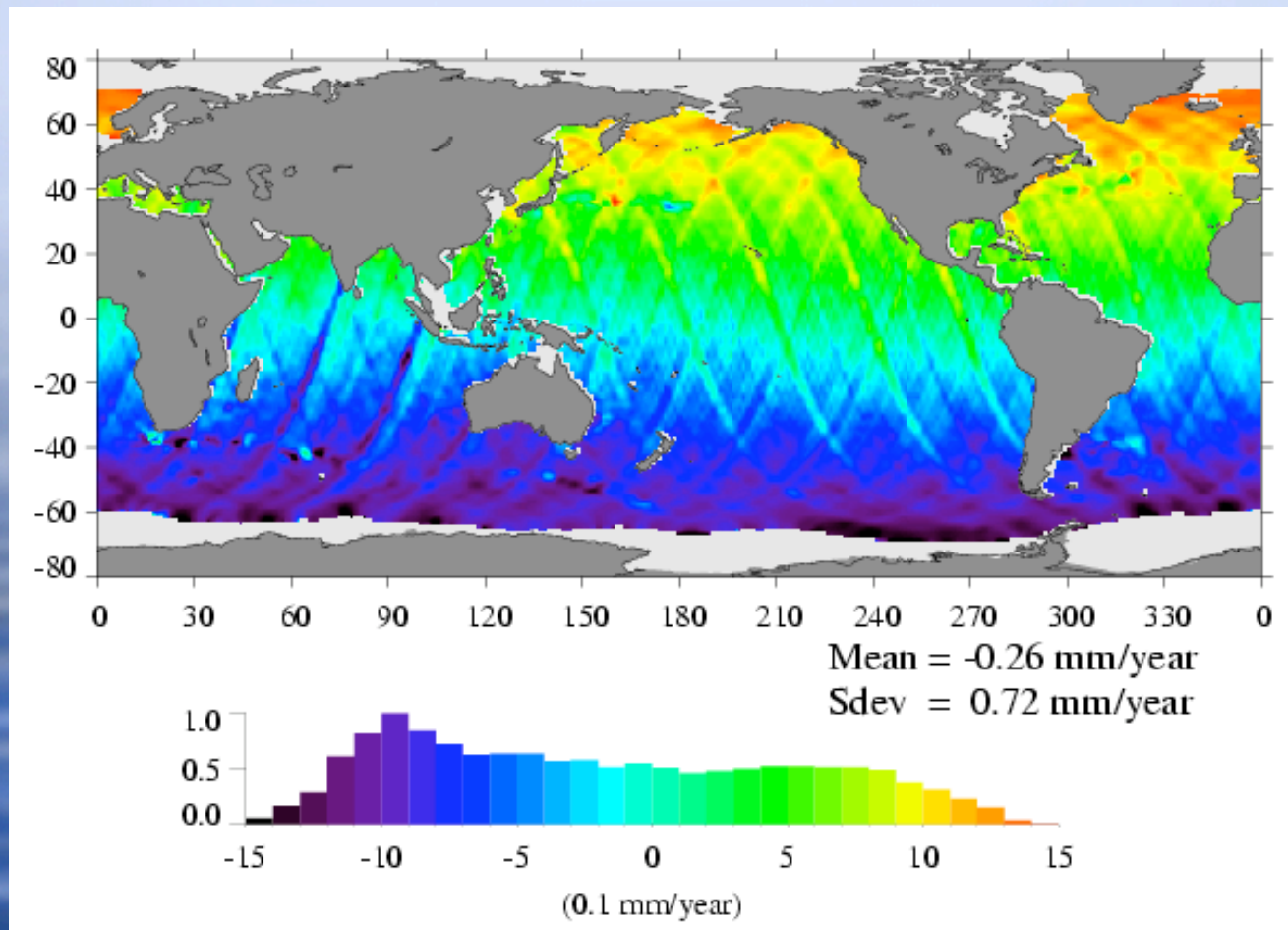


Net sea level change

(Topex-Poseidon, Jason)

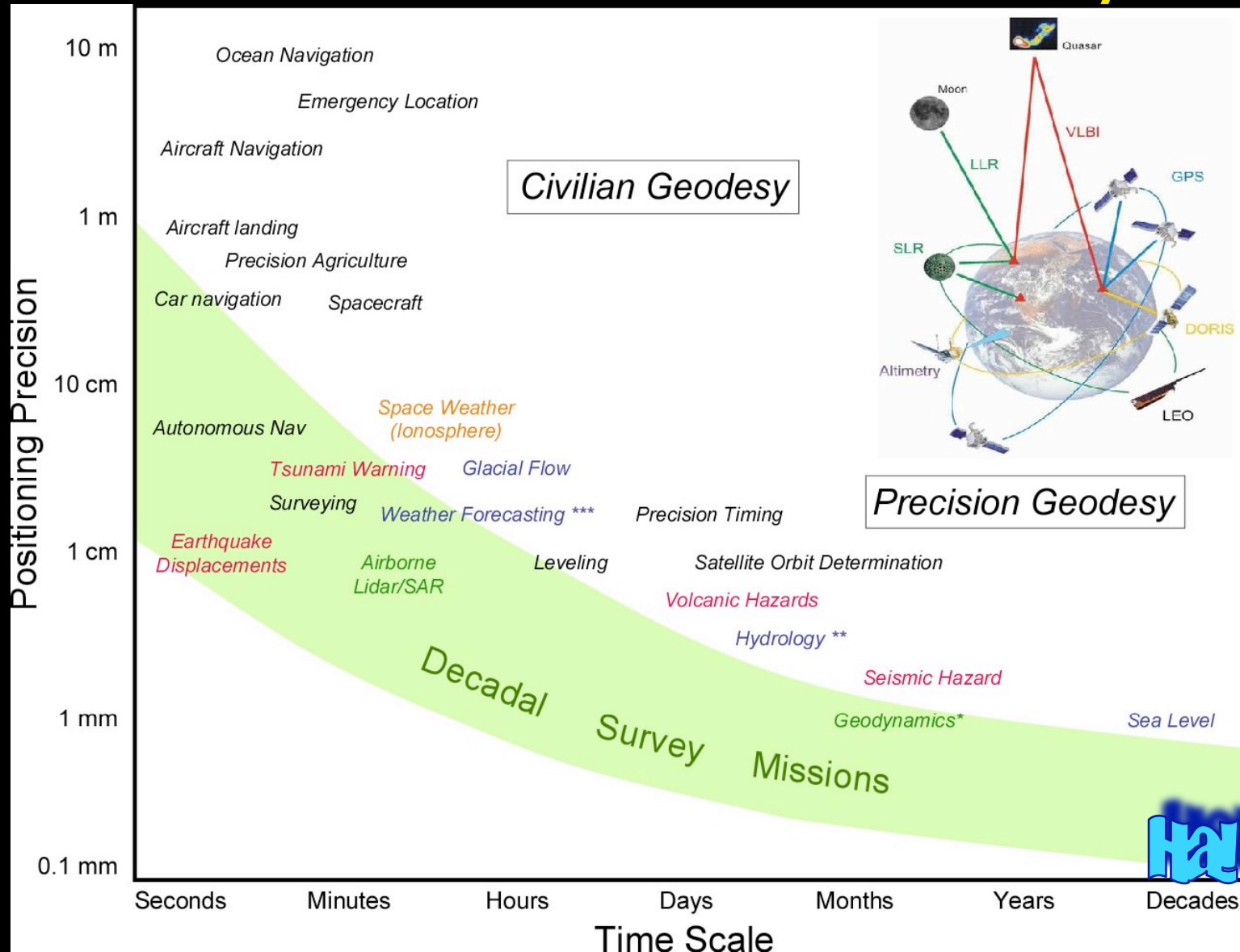


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From Beckley et al. (2007), *GRL*, (Fig 2): Regional **TOPEX (1993-2002)** Sea Surface Height Trend differences from direct impact of the **ITRF2005 (GGM02C)** minus **CSR95 (JGM3)** orbit differences. The positive values in the northern hemisphere indicate a previous underestimation of MSL of up to 1.5 mm/yr in the North Atlantic. The striping in the orbit differences indicates the removal of orbit error through gravity model and other modelling improvements.

Precise Global Geodesy



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The Global Geodetic Observing System (GGOS)

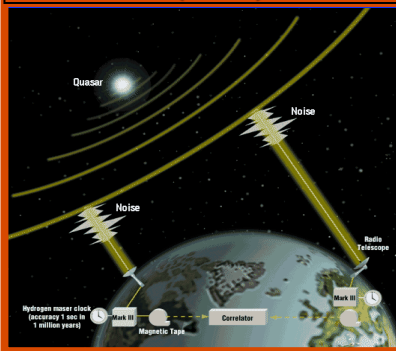
Reference Frame Services and Products

International Terrestrial Reference Frame (ITRF)

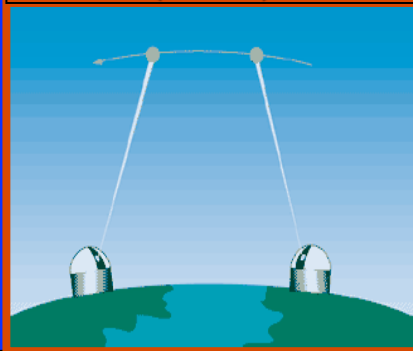
International Earth Rotation Service
(IERS)

Precision GPS Orbits and Clocks, Earth Rotation Parameters, Station Positions

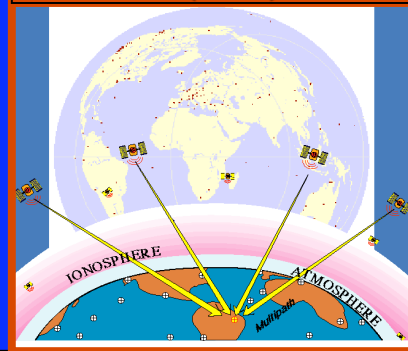
Very Long Baseline
Interferometry
(IVS)



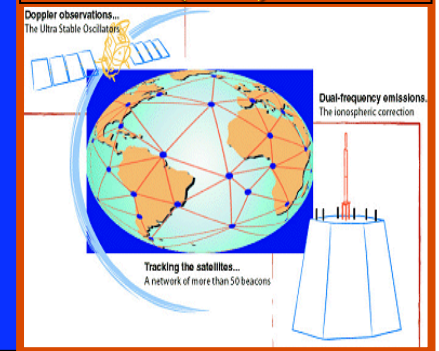
Satellite Laser
Ranging
(ILRS)



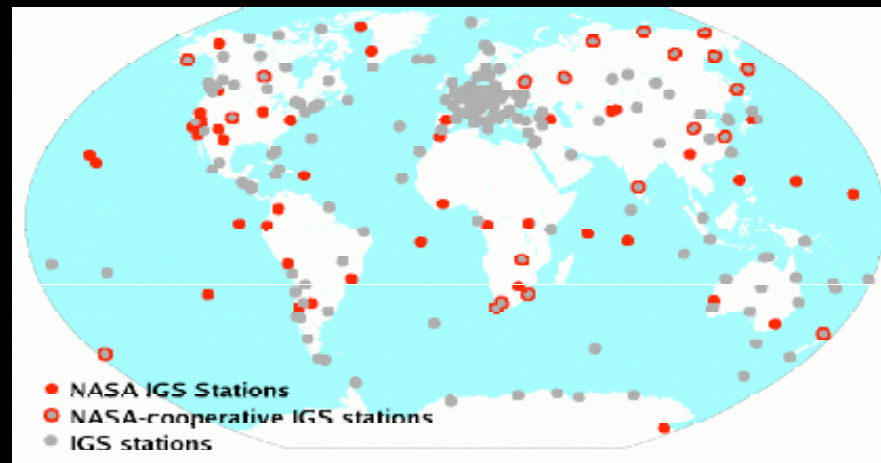
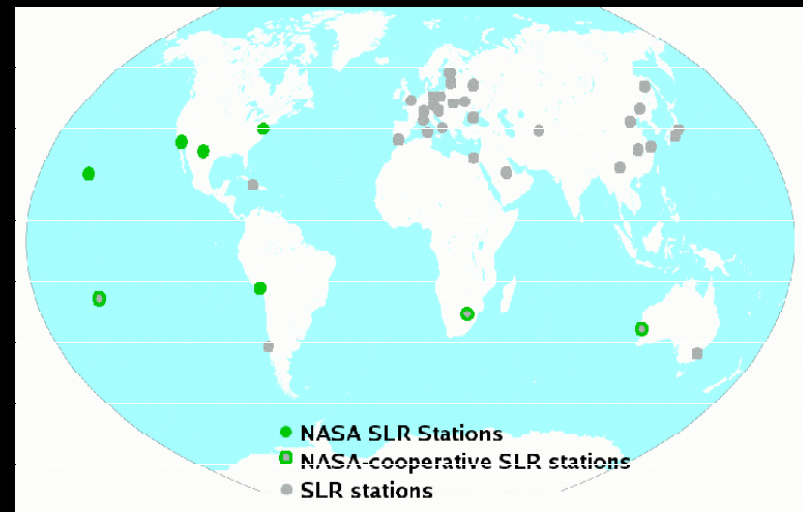
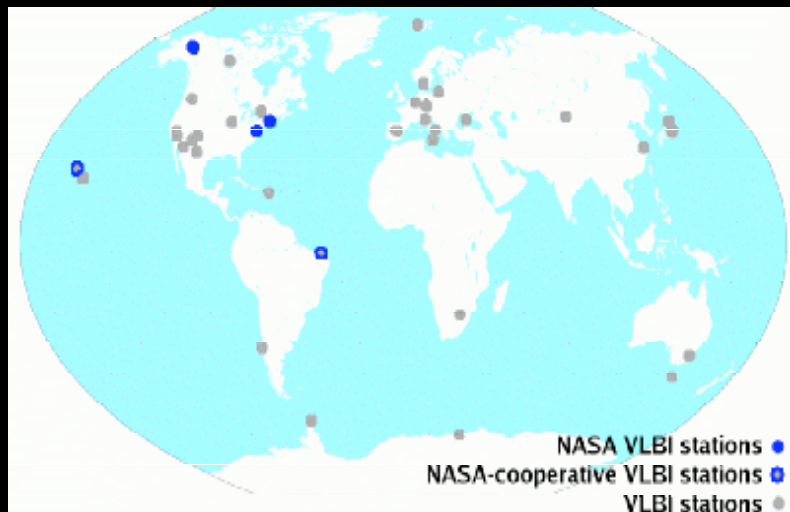
Global Navigation
Satellite Systems
(IGS)



Doppler Orbit Determination
and Radiopositioning
Integrated on Satellite
(IDS)

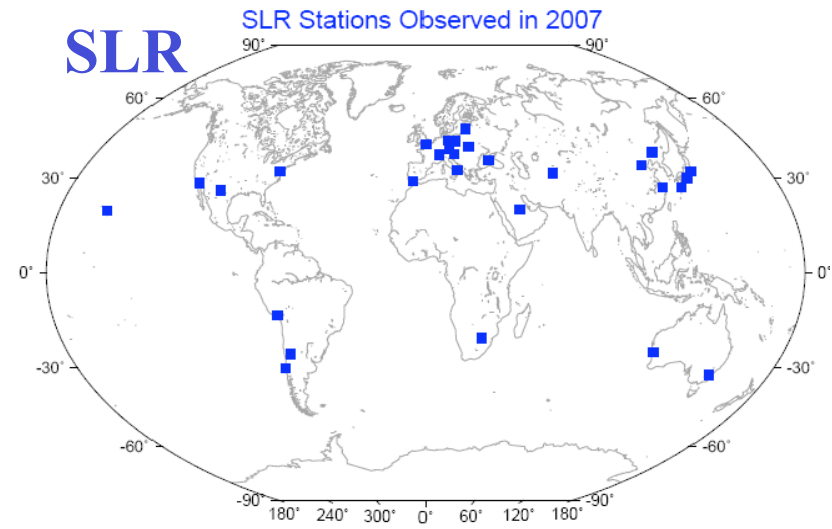
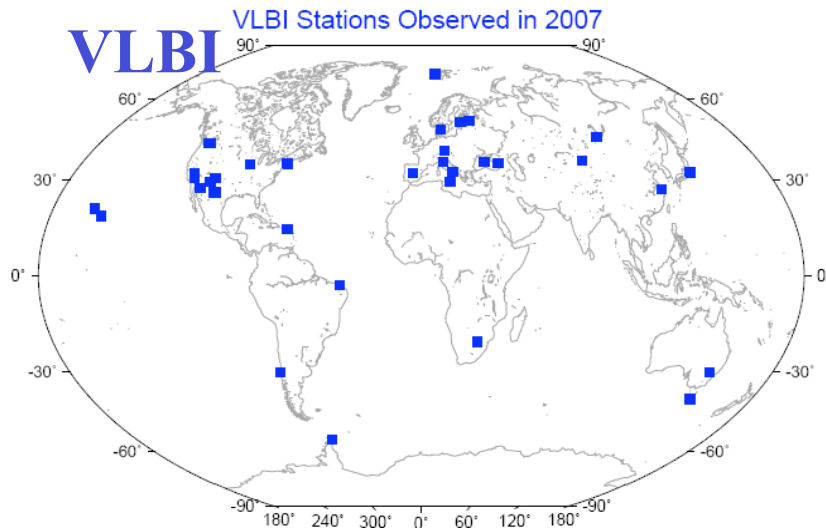


Global networks, at risk

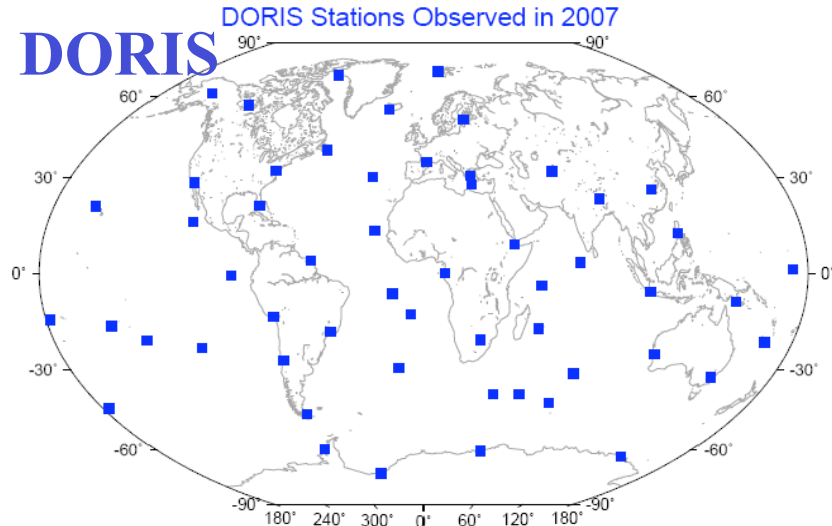
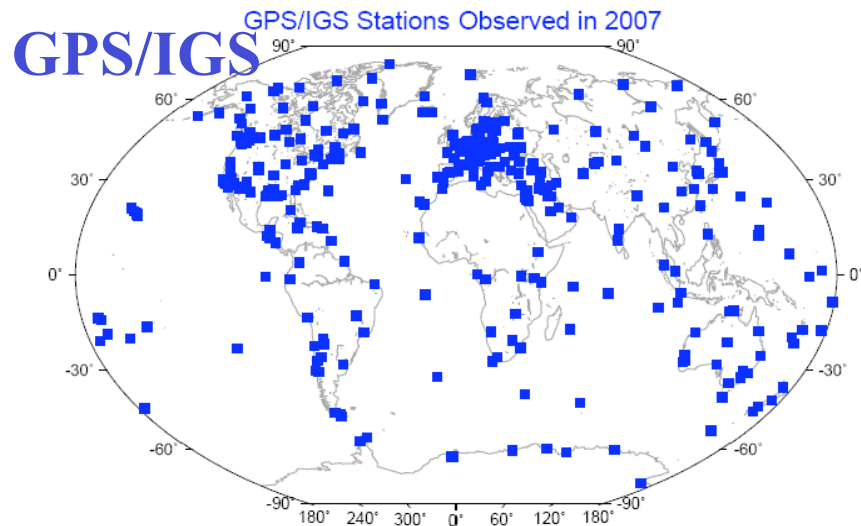


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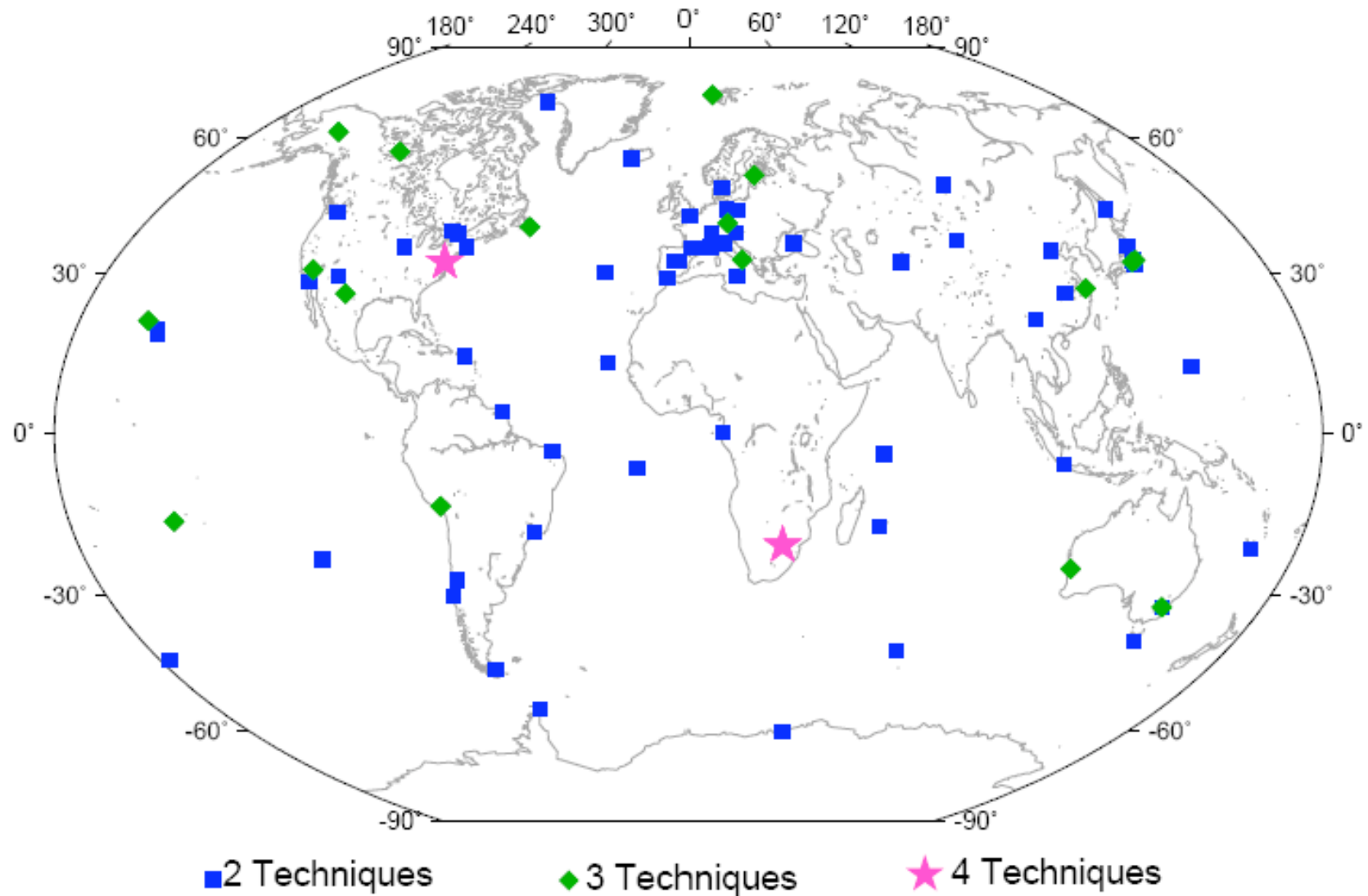
Current networks: stations observed in 2007



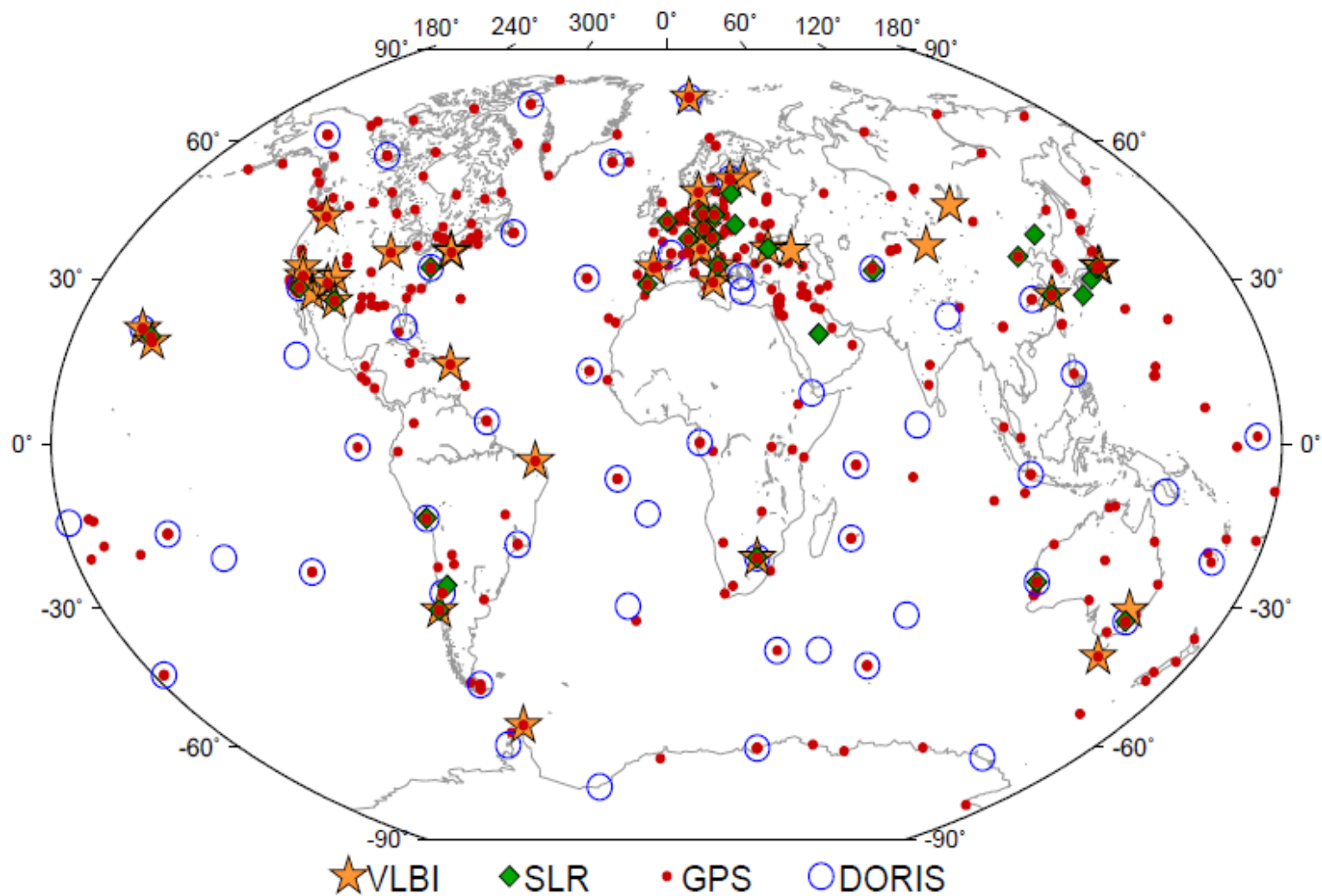
Weaknesses & Threats: SLR & VLBI poor networks



Current Co-locations (2007)



Current ITRF Network



Co-location Site

- Site where two or more space geodesy close instruments (hundred meters) are operating
- Surveyed in three dimensions, using classical or GPS geodesy
- Differential coordinates (DX, DY, DZ) are available

$$DX_{(GPS,VLBI)} = X_{VLBI} - X_{GPS}$$



GPS

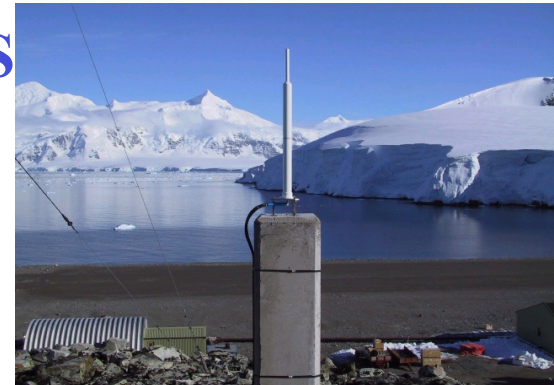


VLBI

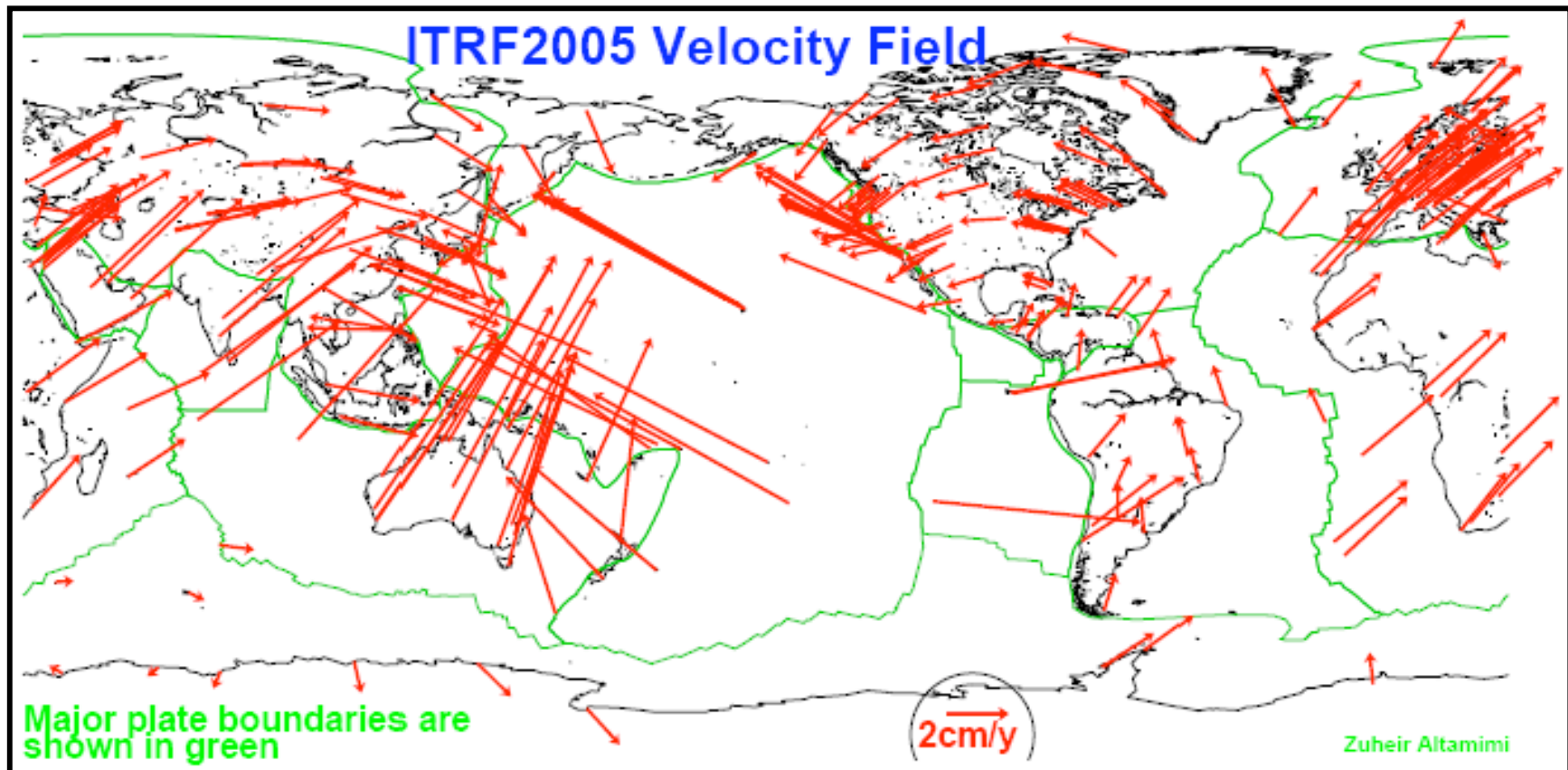
SLR

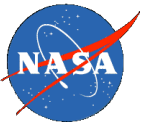


DORIS

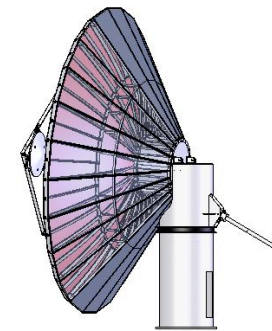
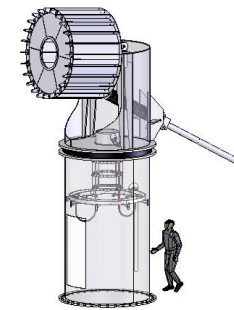


ITRF2005 Site Velocities with $\sigma < 3\text{mm/y}$

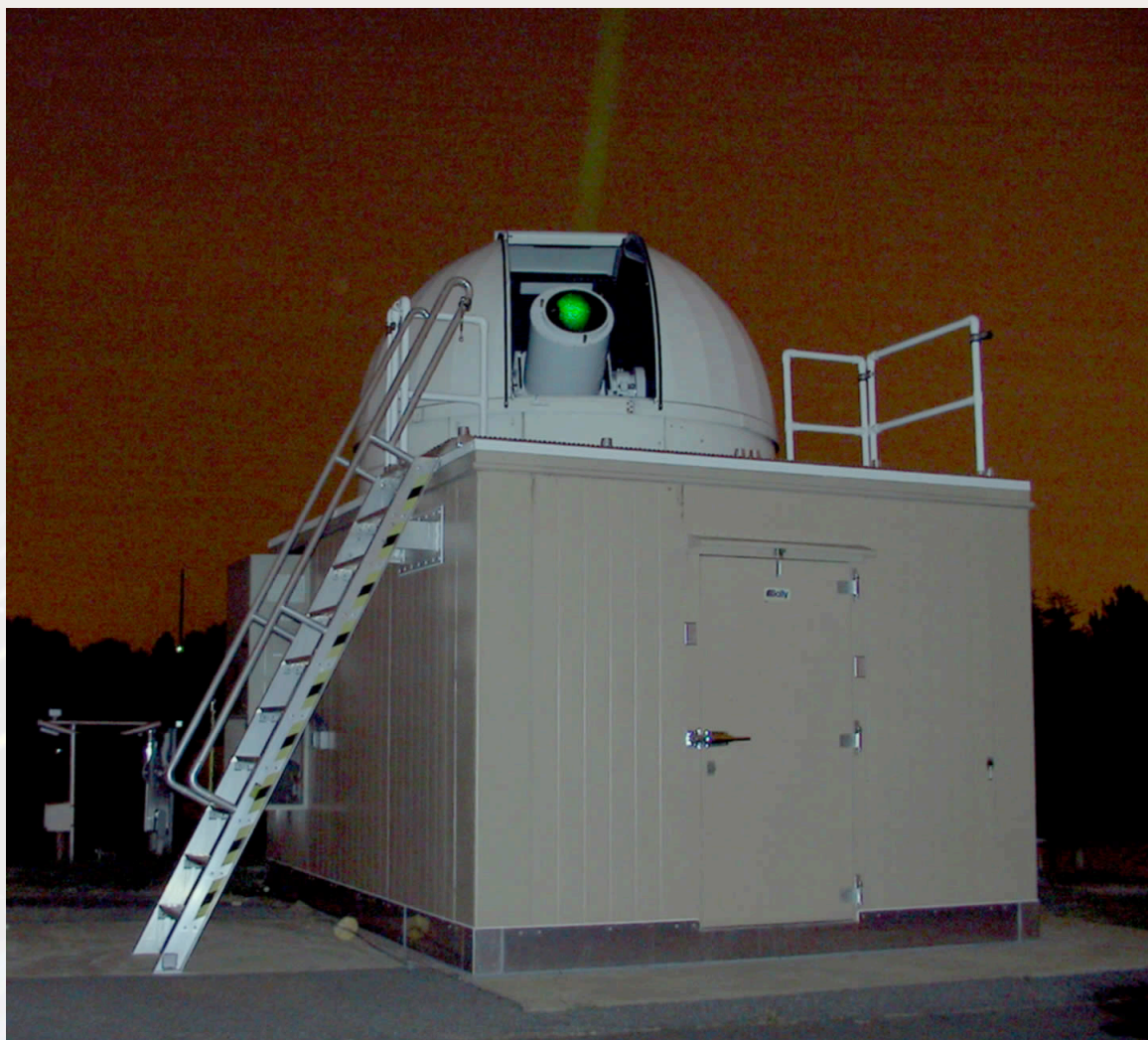




Patriot 12-m VLBI Antenna



NASA Next Generation SLR System



NASA's Next Generation SLR (NGSLR), GGAO, Greenbelt, MD

Hydrogen maser clock
(accuracy 1 sec in
1 million years)

Mark III

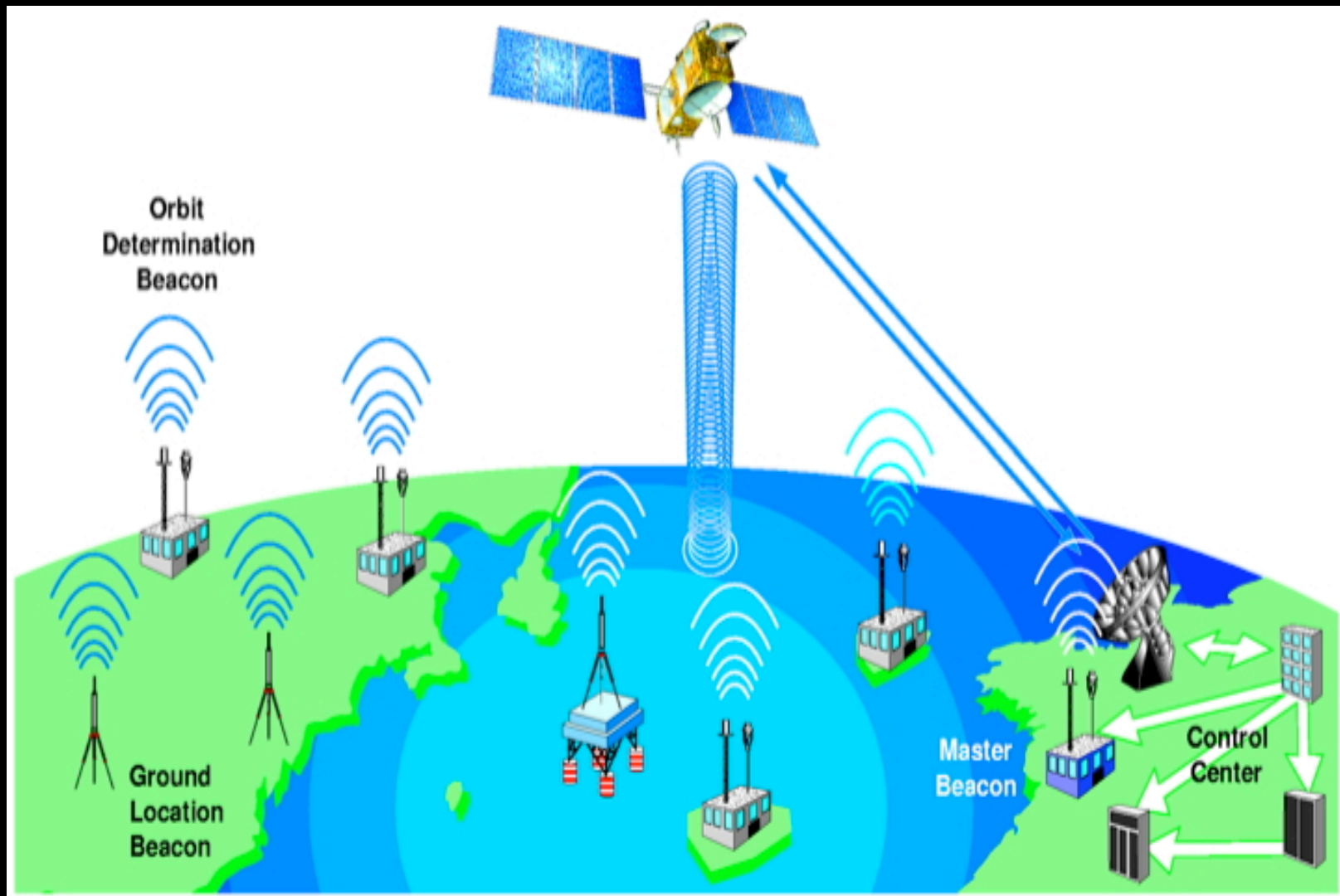
Magnetic Tape

Geodetic satellites



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DORIS system



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Strengths :

Contribution of Geodetic Techniques to the ITRF

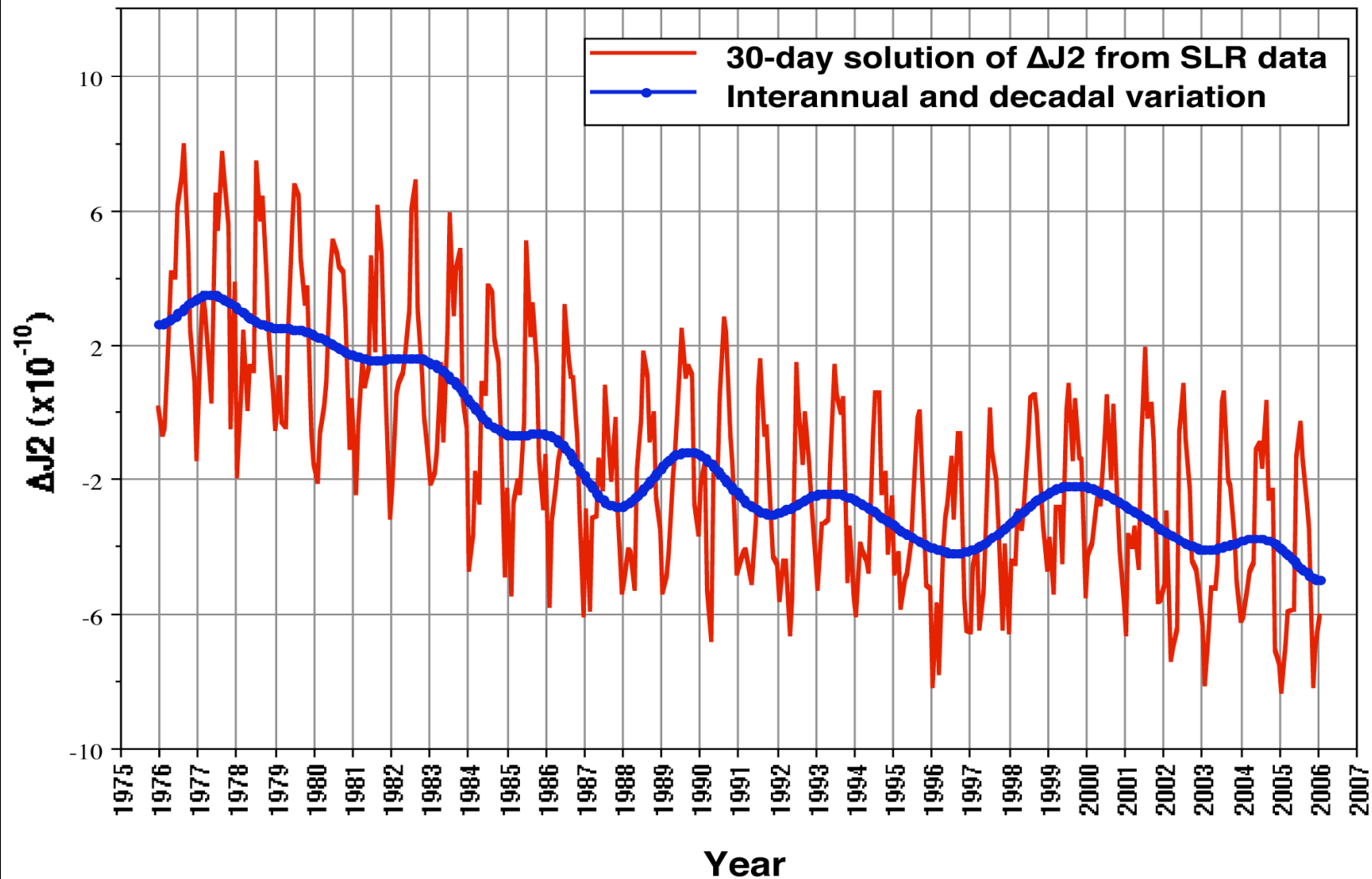
Mix of techniques
is fundamental to
realize a frame that
is stable in origin,
scale, and with
sufficient coverage

From:
Ries et al., 2005,
(Modified)

| Technique Signal Source Obs. Type | VLBI Microwave Quasars Time difference | SLR Optical Satellite Two-way absolute range | GPS Microwave Satellites Range change | DORIS |
|--|--|---|---|--------------|
| Celestial Frame & UT1 | Yes | No | No | No |
| Polar Motion | Yes | Yes | Yes | Yes |
| Scale | Yes | Yes | Yes | Yes |
| Geocenter ITRF Origin | No | Yes | Yes | Yes |
| Geographic Density | No | No | Yes | Yes |
| Real-time & ITRF access | Yes | Yes | Yes | Yes |
| Decadal Stability | Yes | Yes | Yes | Yes |

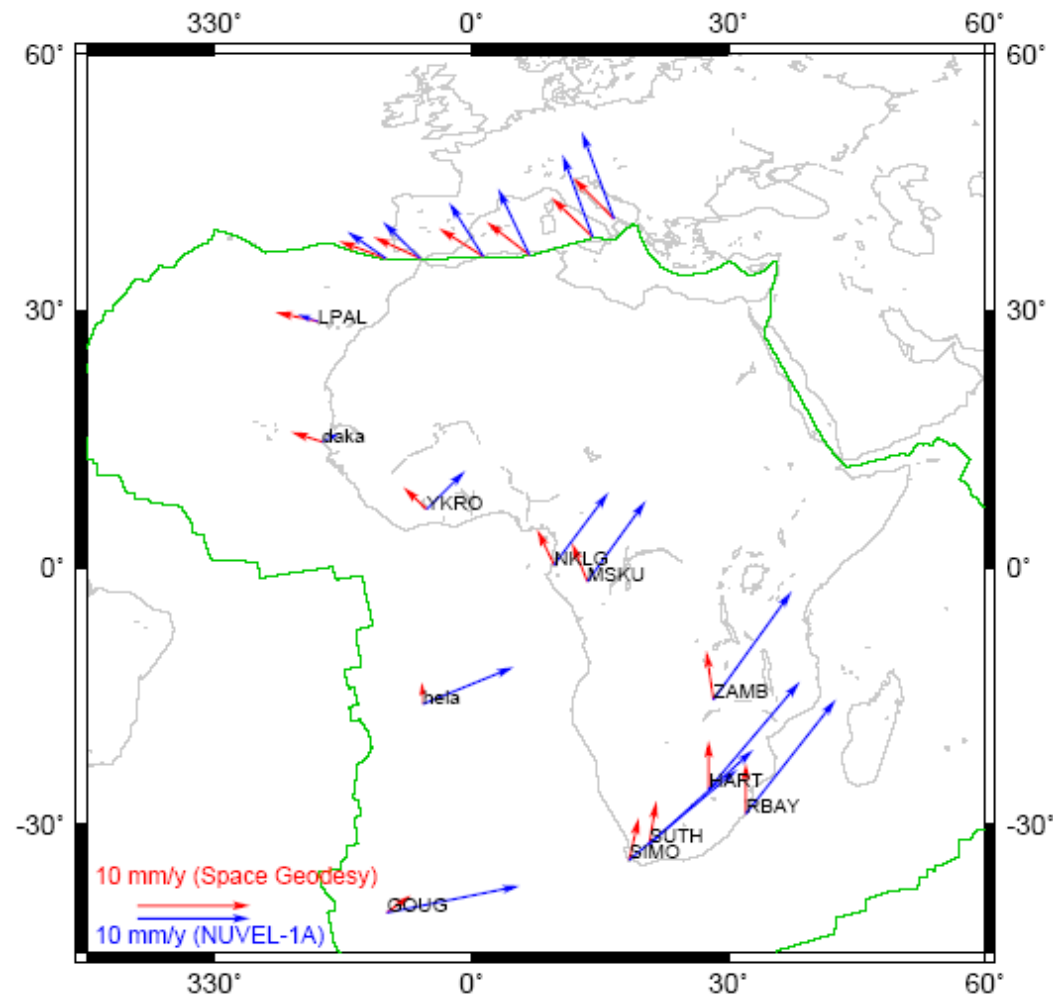
ITRF Orientation time evolution Yes Yes **Yes**

Oblateness of the Earth from SRL



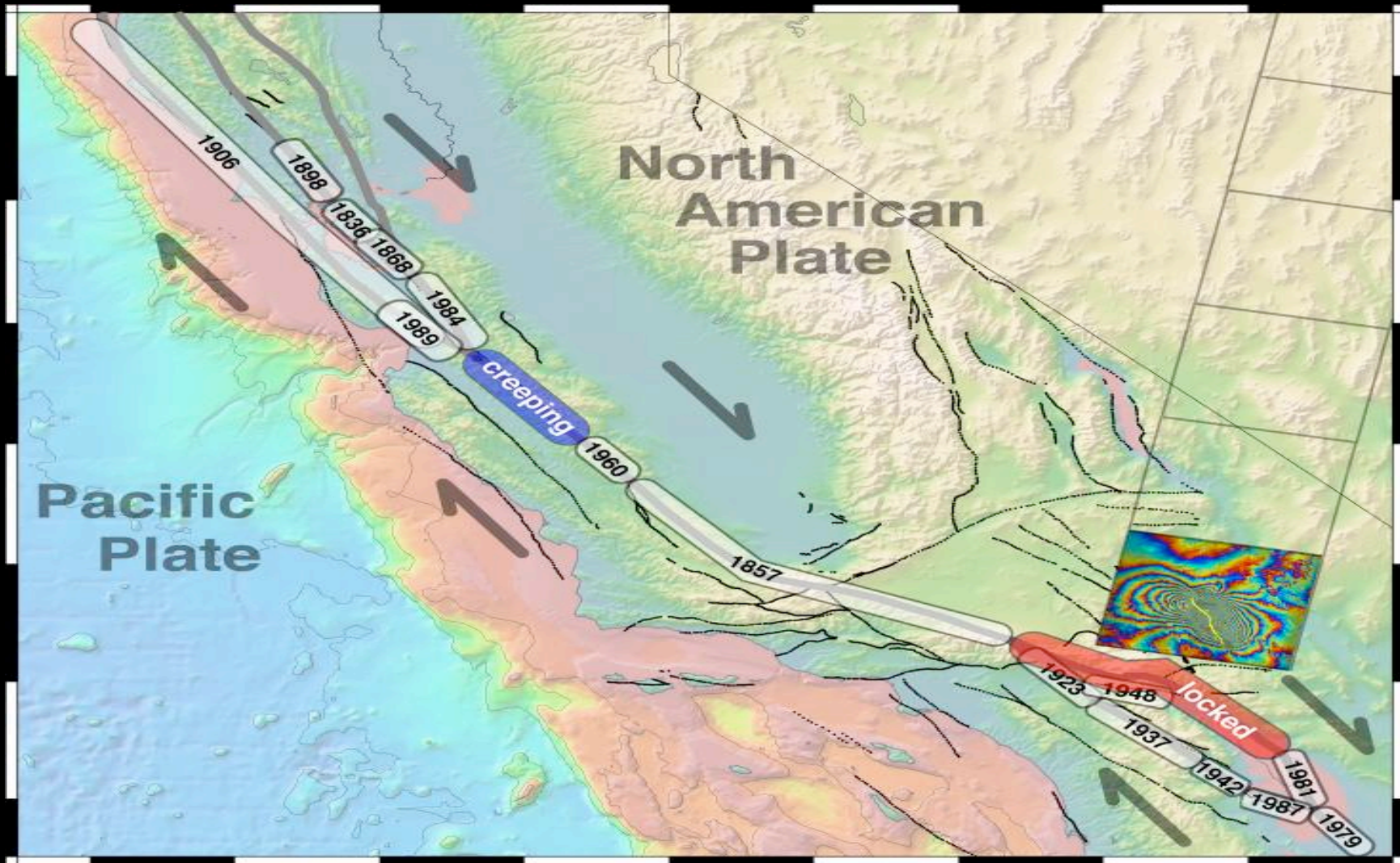
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Mouvement AFRC (NUBI) – EURA



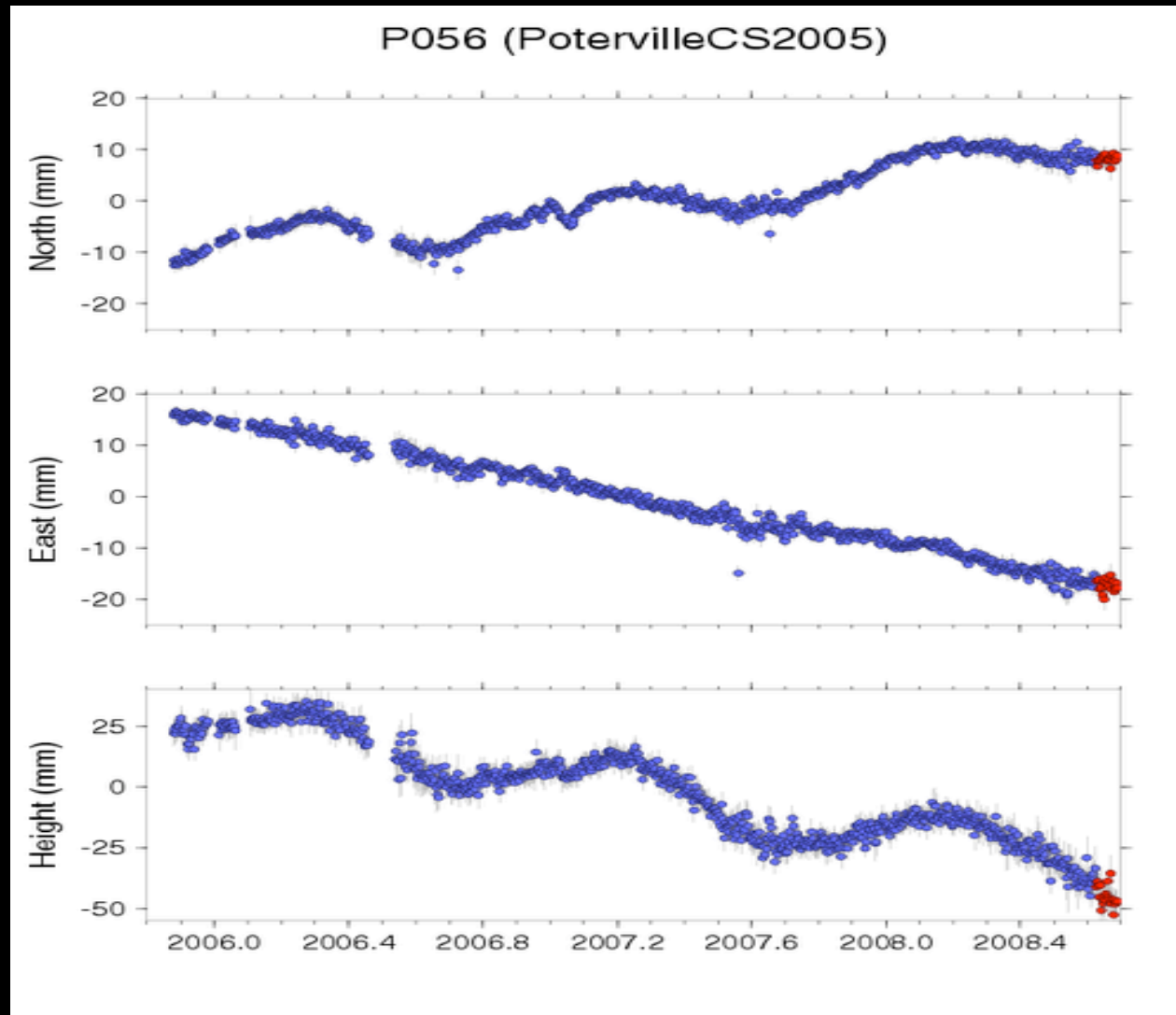
Nubia-Eurasia velocity ~50% slower than NUVEL1-A prediction

California seismic hazard



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GPS vertical ... Pumping!



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Land Subsidence at Lost Hills



Ground subsidence in the Belridge and Lost Hills oil fields, west-northwest of Bakersfield, California, based upon the 18 year difference between USGS and SRTM DEMs. The image morphs between the two DEMs (with great vertical exaggeration) and uses a Landsat image overlay.

Hydrogen maser clock
(accuracy 1 sec in
1 million years)

Magnetic Tape



NRC NRPGI Panel, Meeting 2, Boulder, CO, 11-12 June, 2008



GPS Science in Support of Earthquake Research The Southern California Integrated GPS Network (SCIGN)

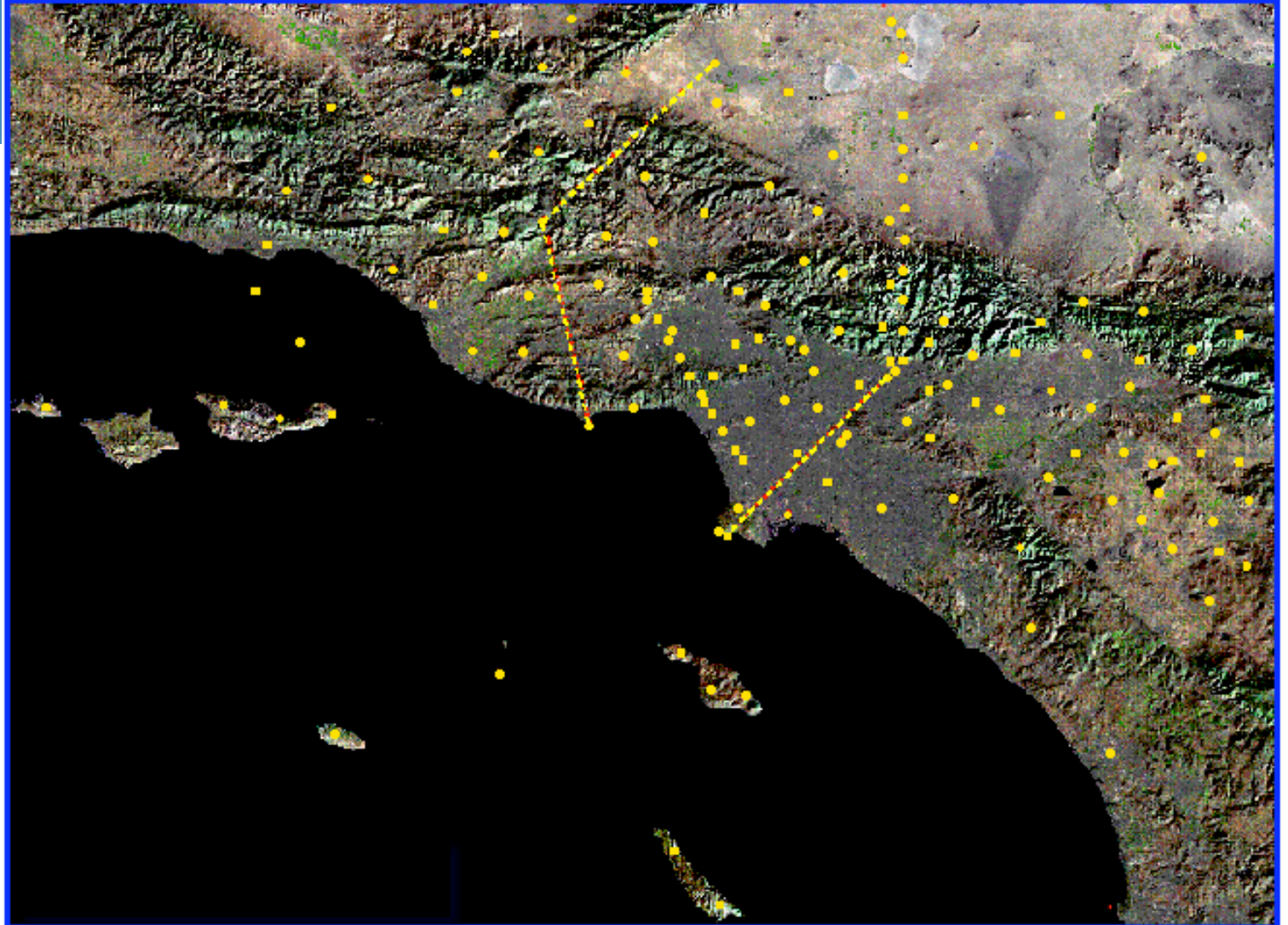
W.M.
KECK
Foundation



USGS

SC/EC

JPL





Geodetic Imaging Science and Technology For Tectonics and Hydrology (GPS plus InSAR)

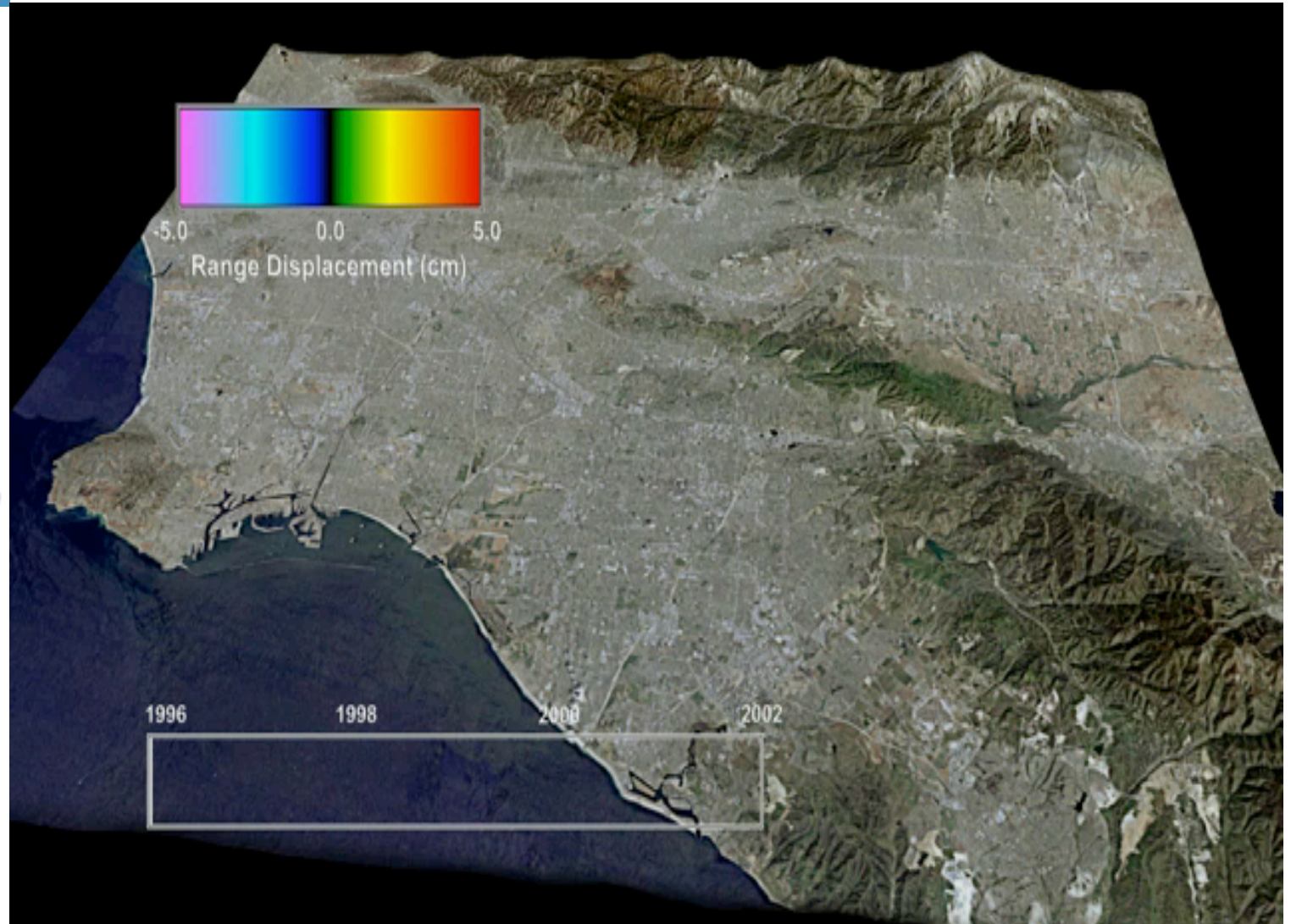
W.M.
KECK
Foundation



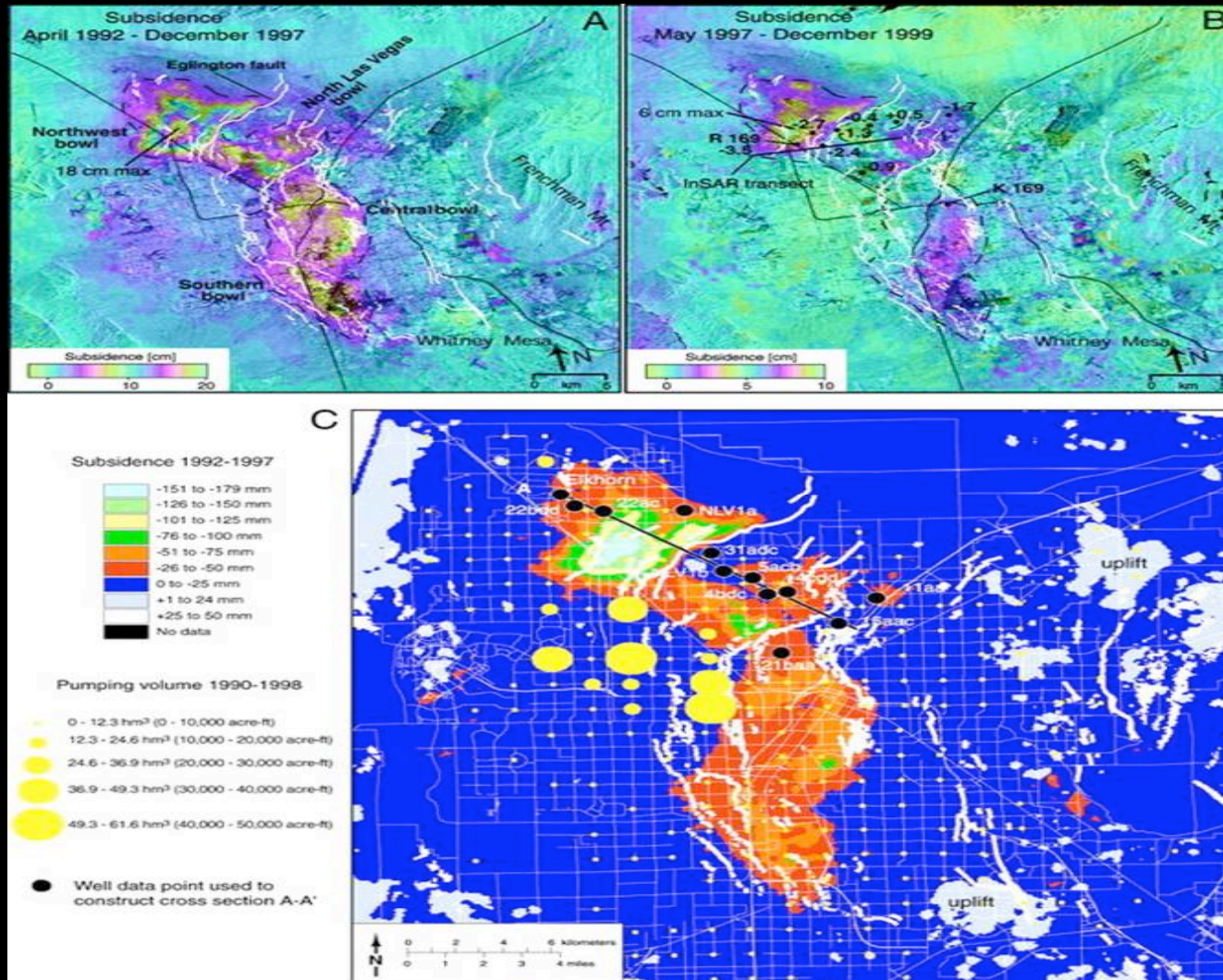
USGS

SC/EC

JPL

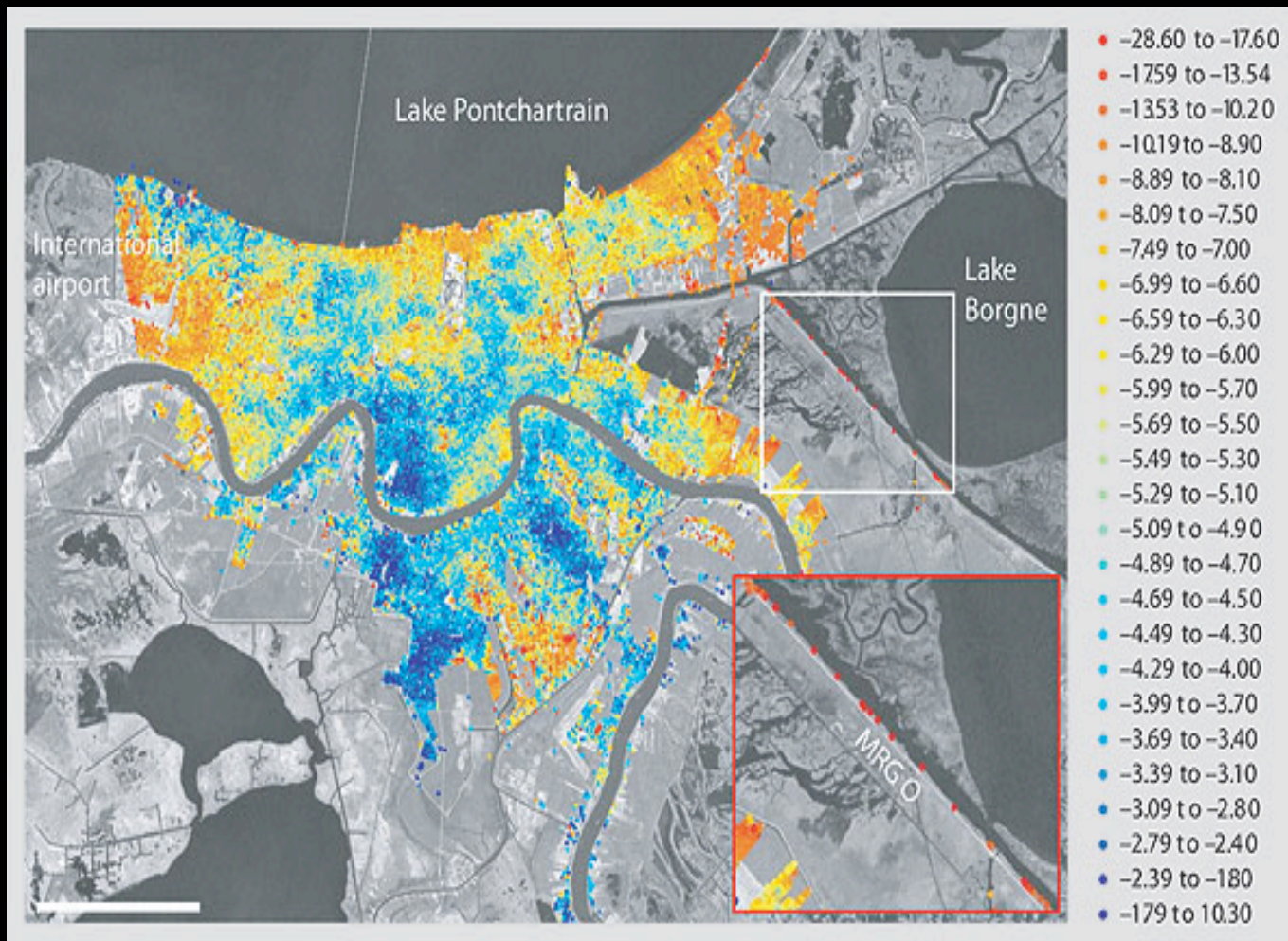


Water table, Las Vegas



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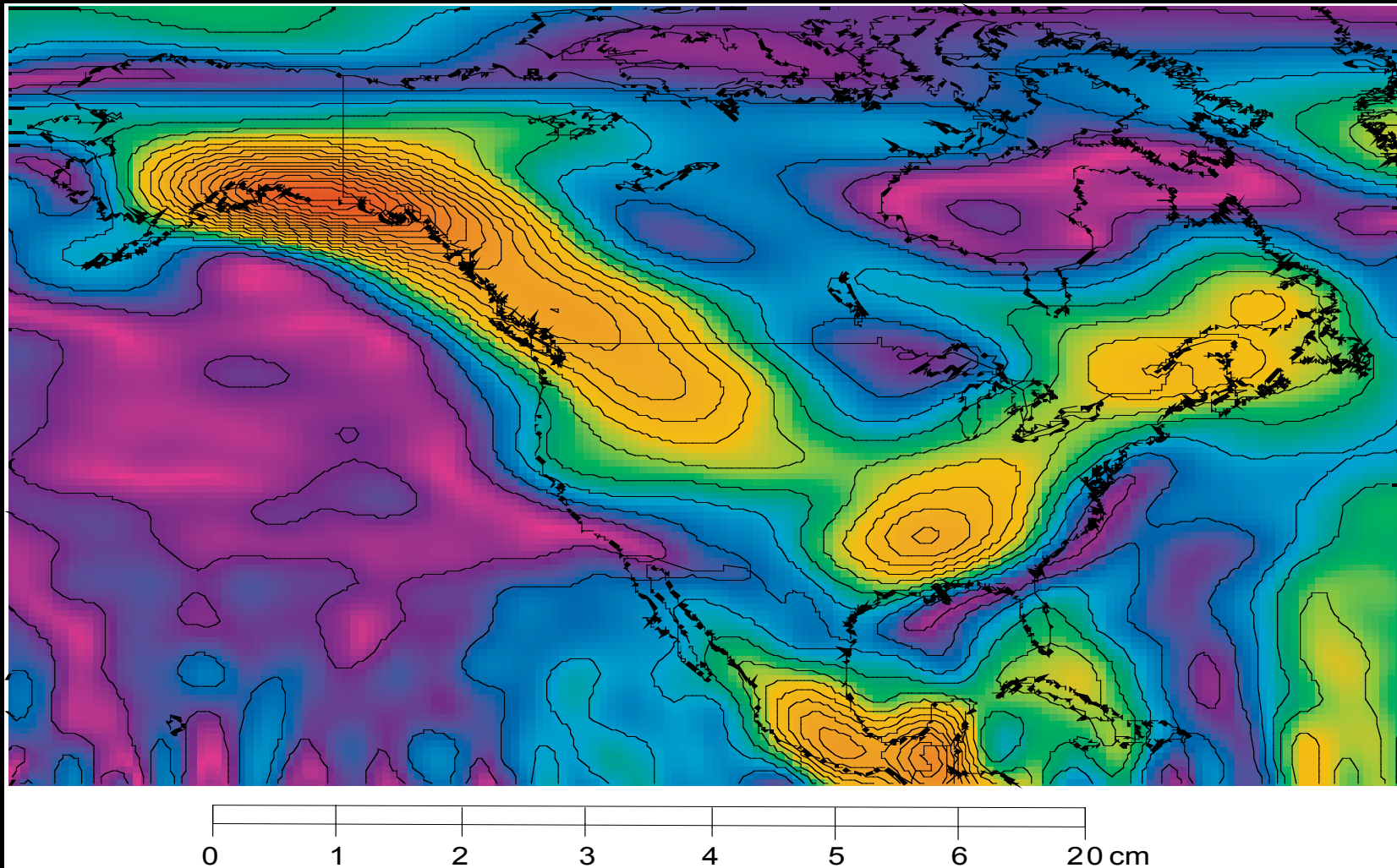
Subsidence, New Orleans



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Stored water annual cycle

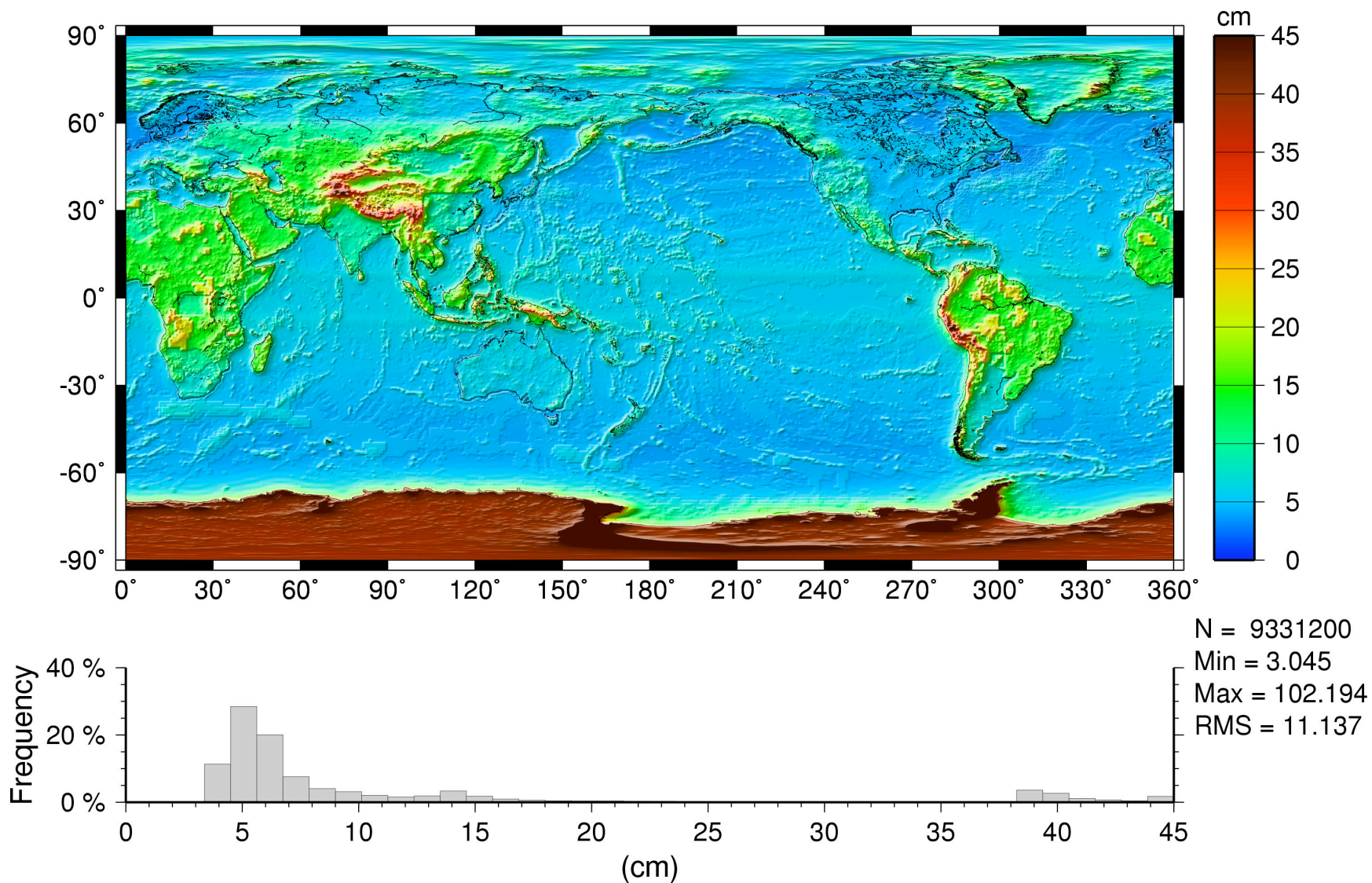
(Grace, 04/02 to 06/08)



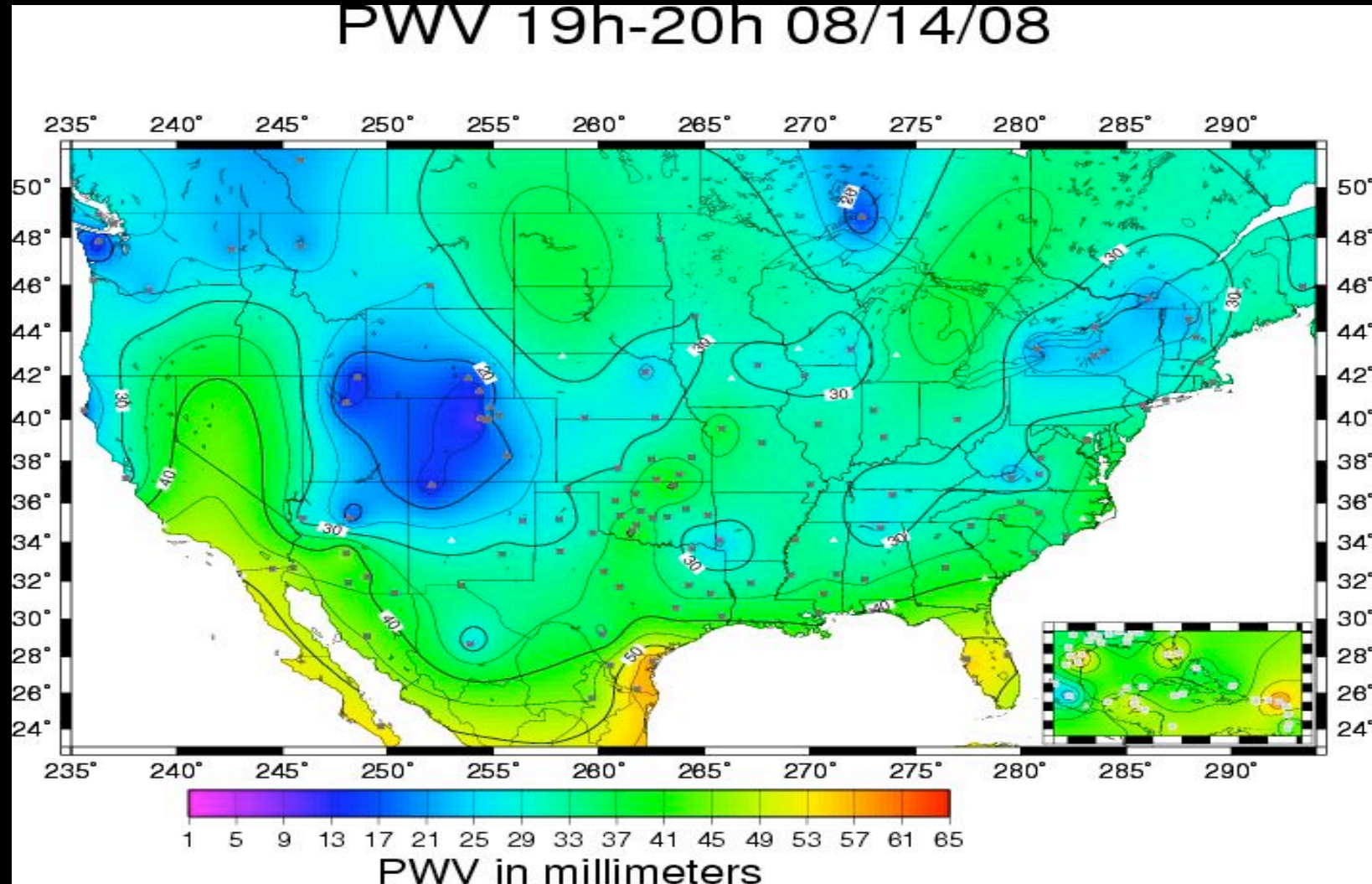
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► 5'×5' N Commission Error: EGM08 (Nmax=2159)

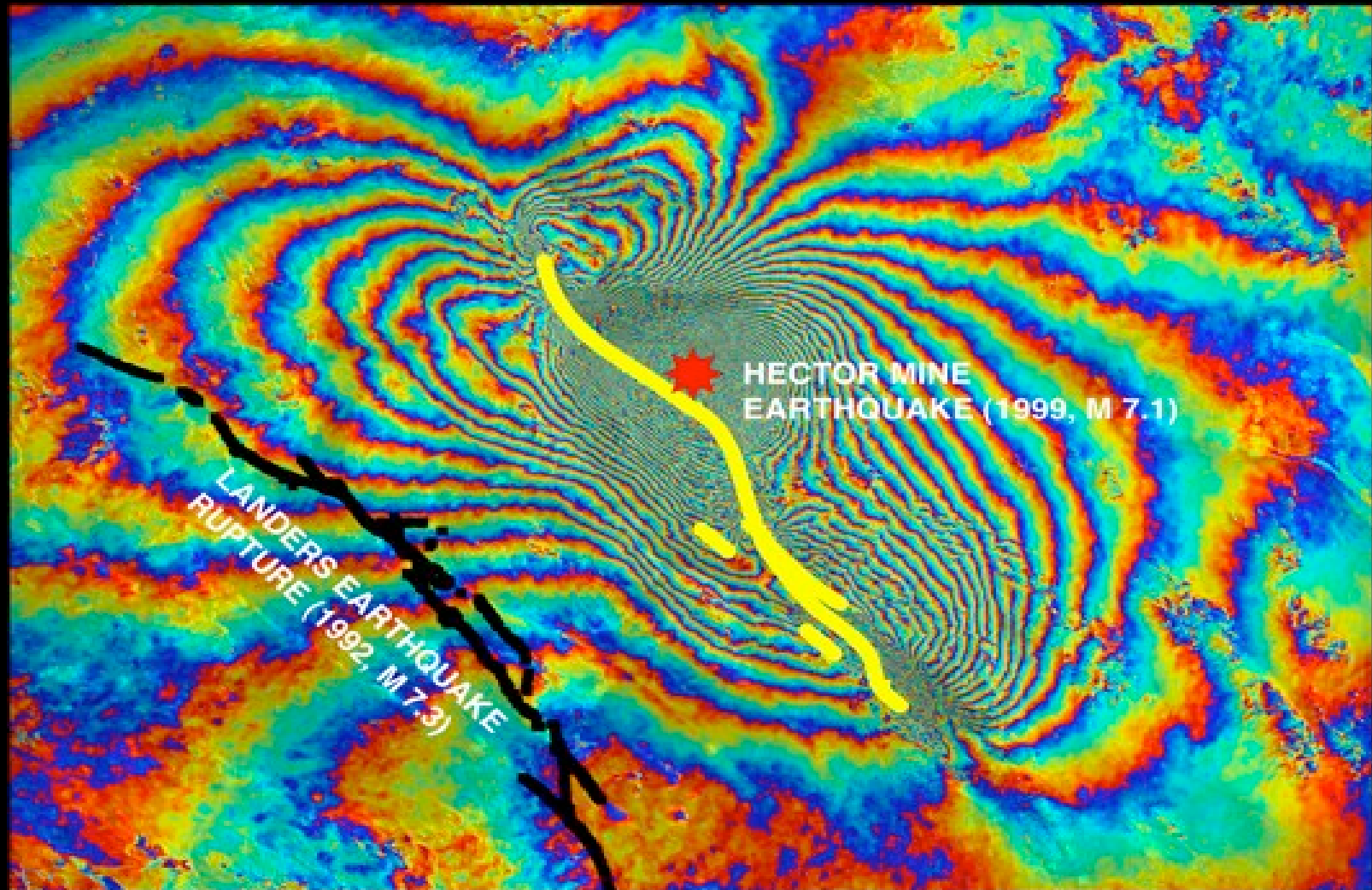


PVW from GPS ... A freebee?



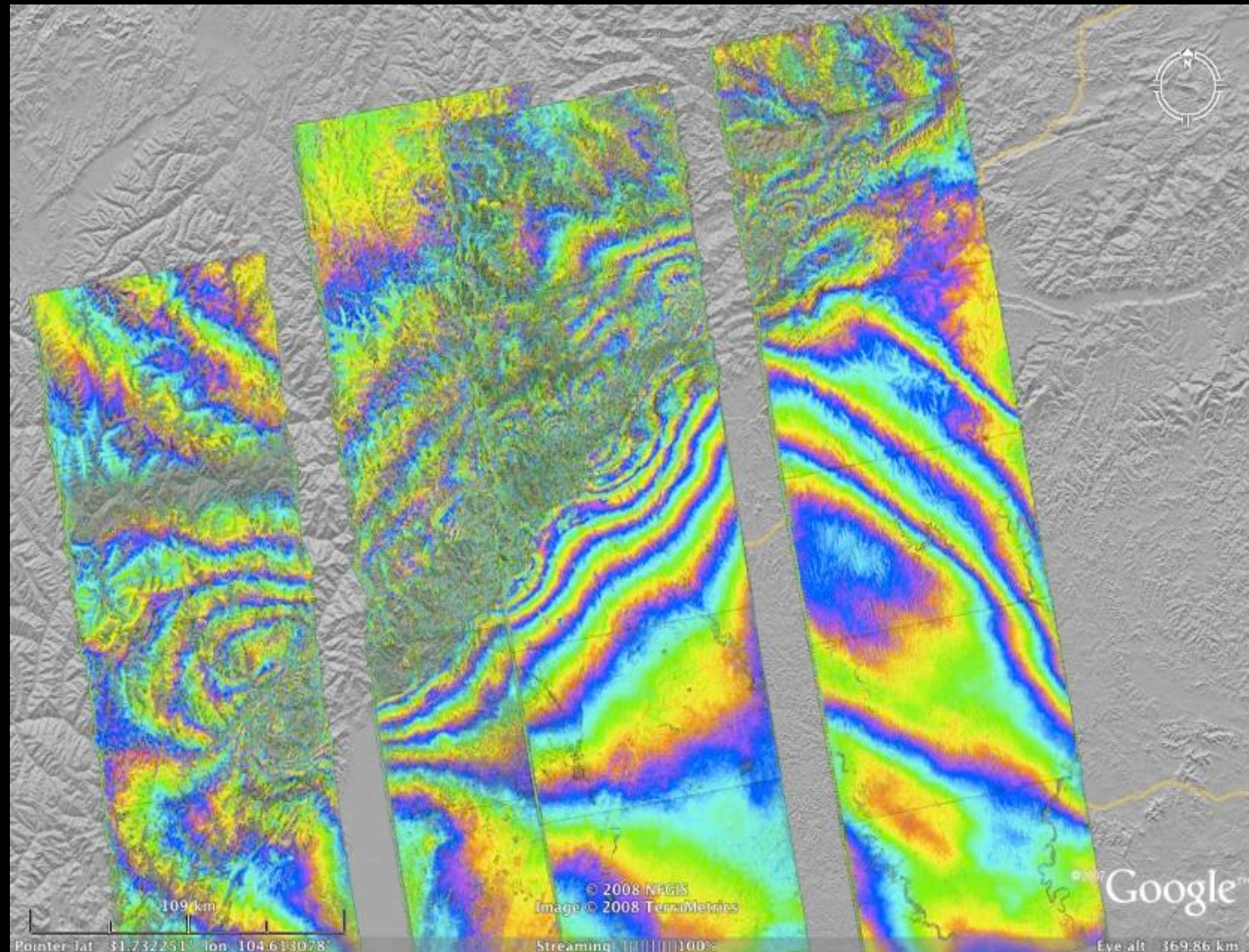
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Hector Mine, 1999



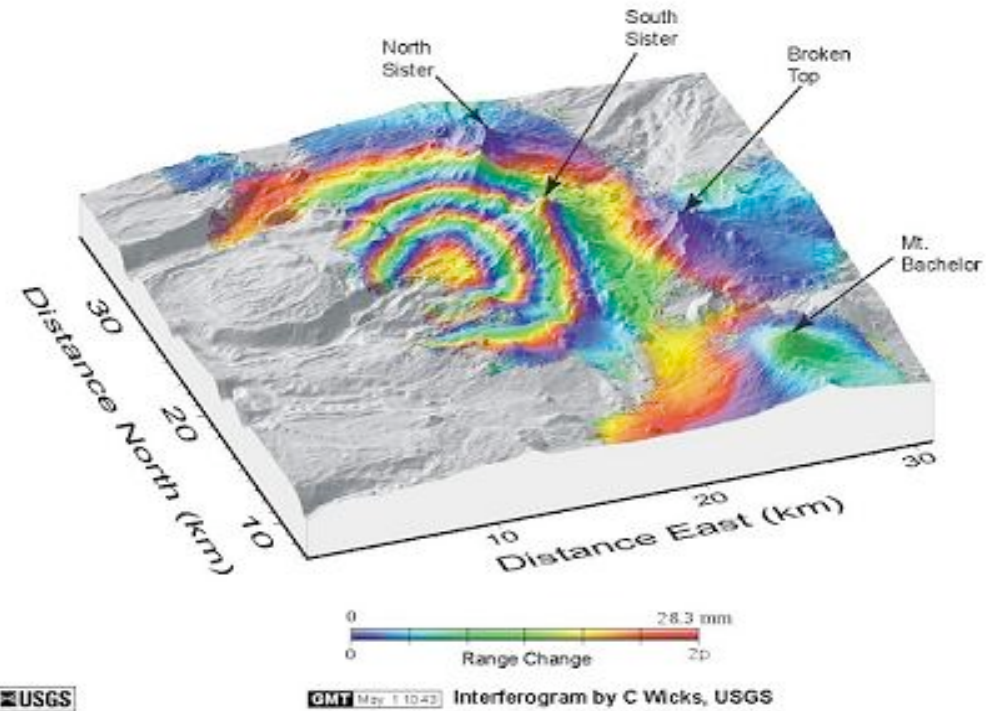
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ALOS- Wenchuan 05-12-2008



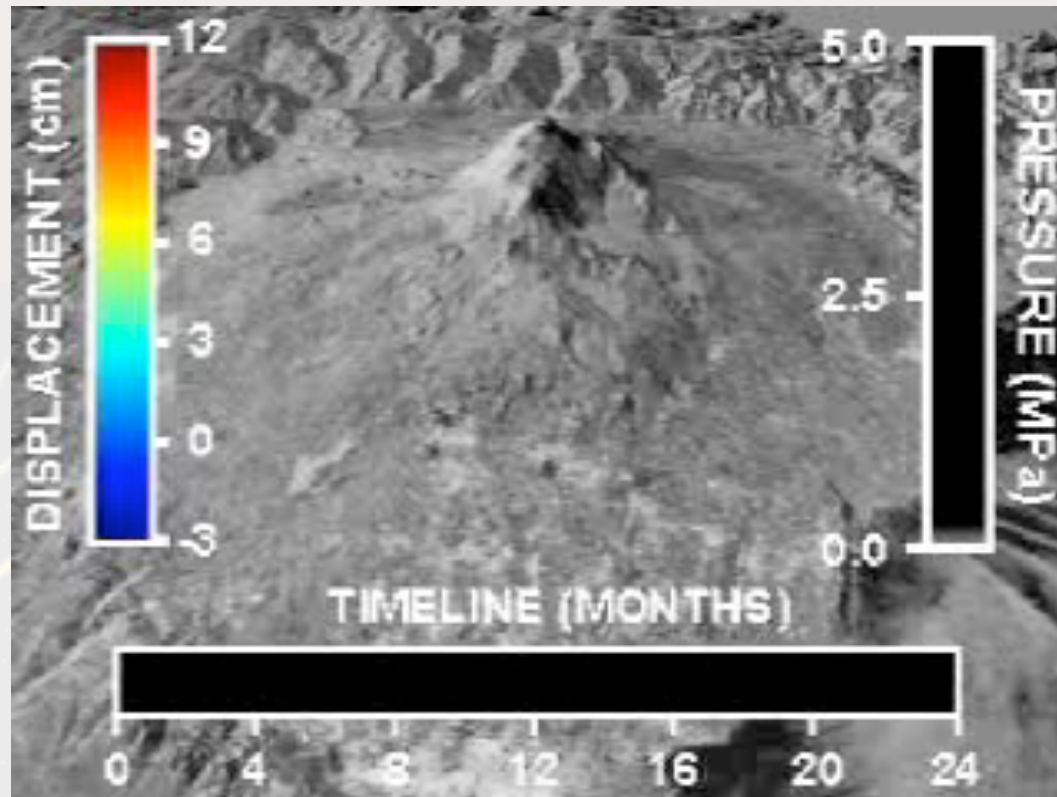
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Volcanic Hazards



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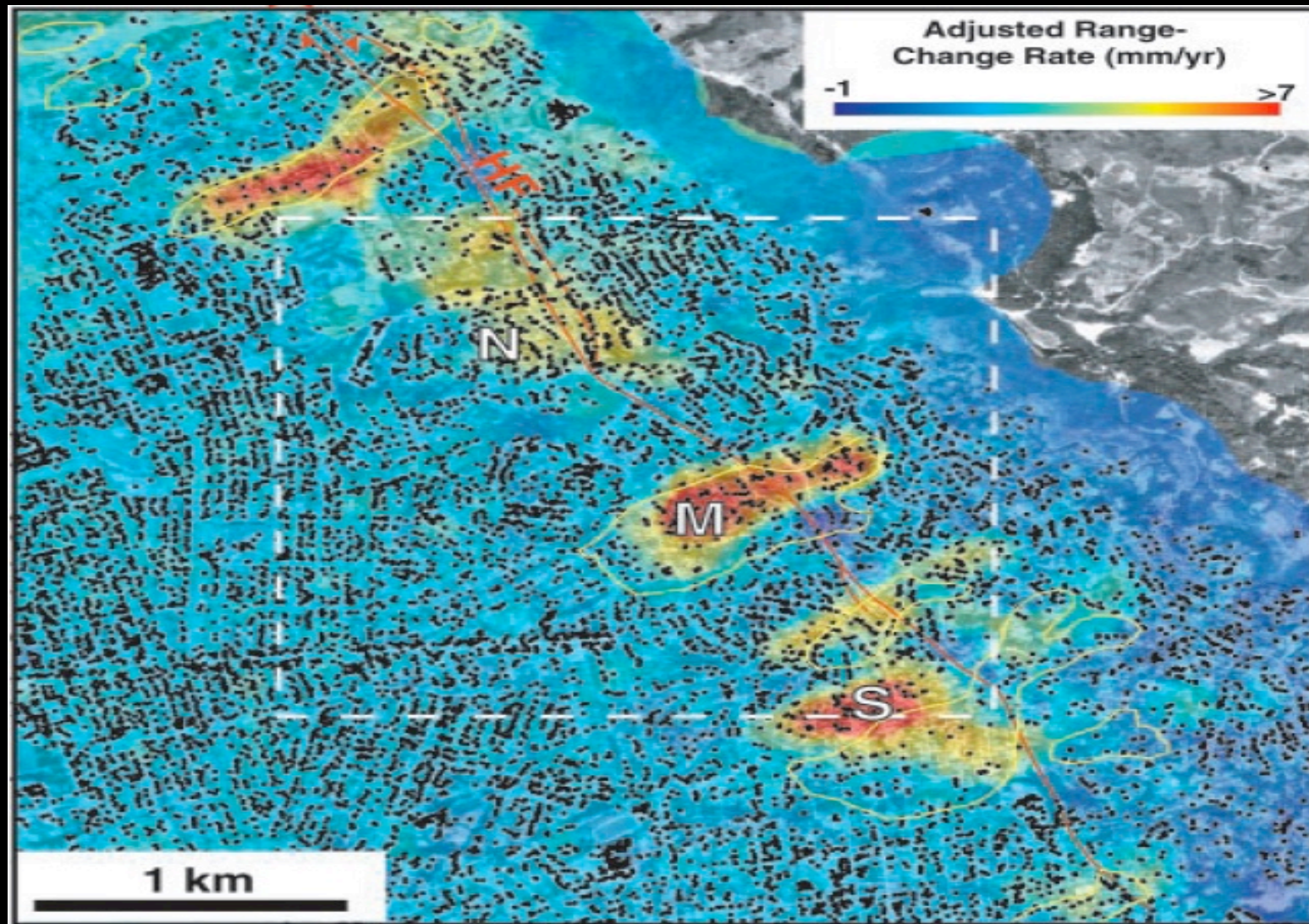
Inflation of Mt. Etna, Italy



InSAR observations of pre-eruptive deformation from 1993-1995 with inferred pressure increase. The volcano erupted in the summer of 1995.



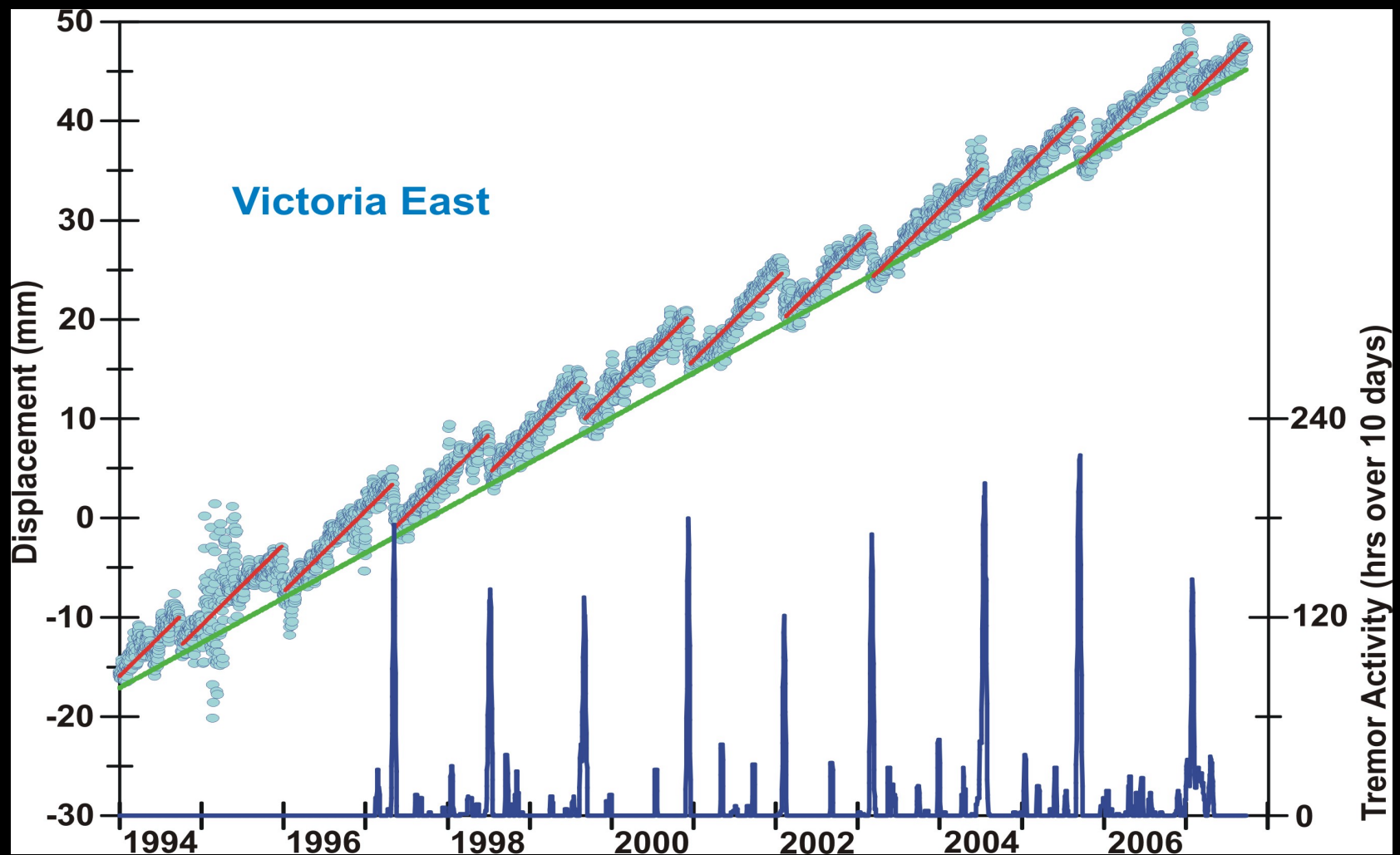
Berkeley landslides ('92-'01)



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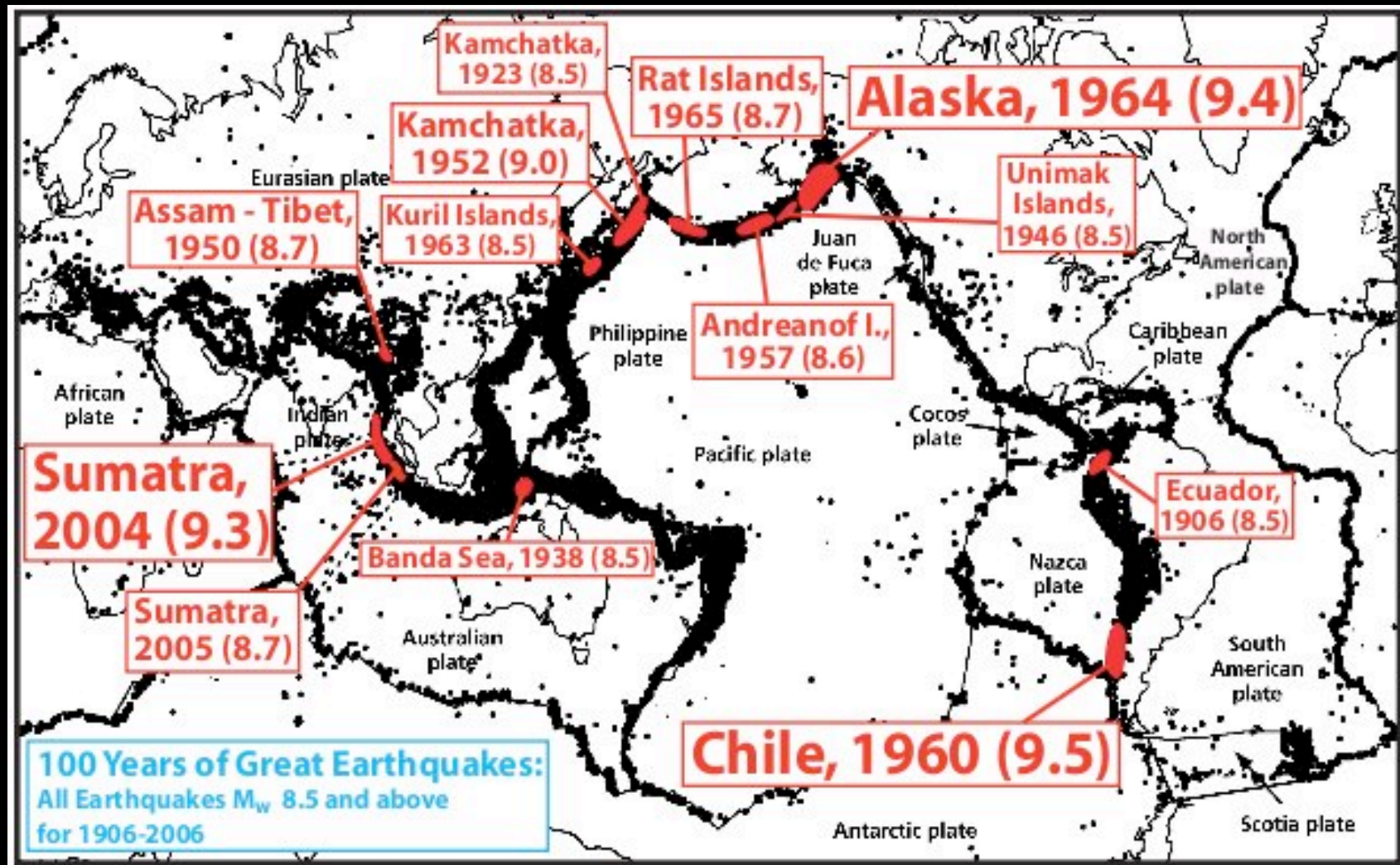


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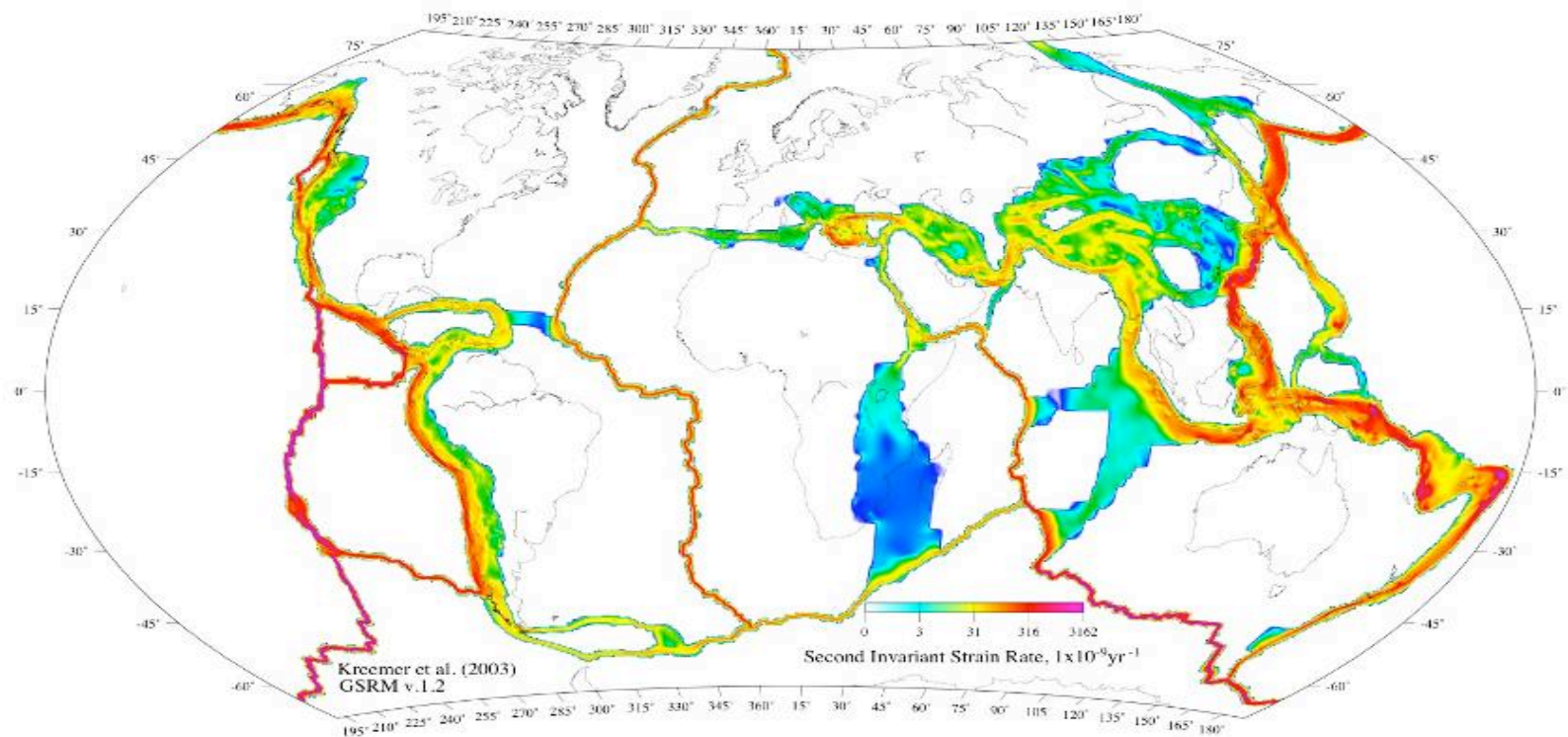
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100 years of great earthquakes



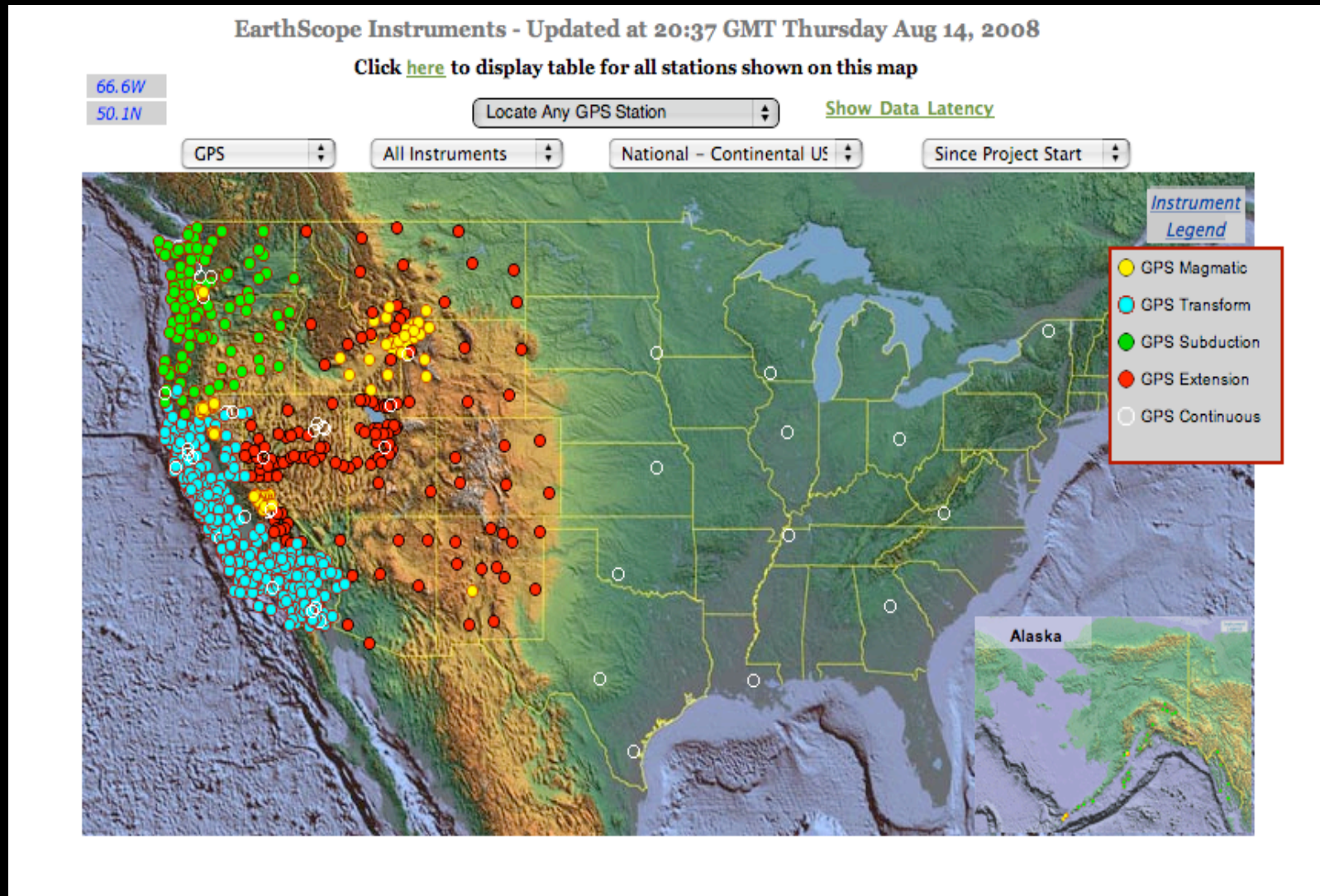
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2nd invariant strain tensor



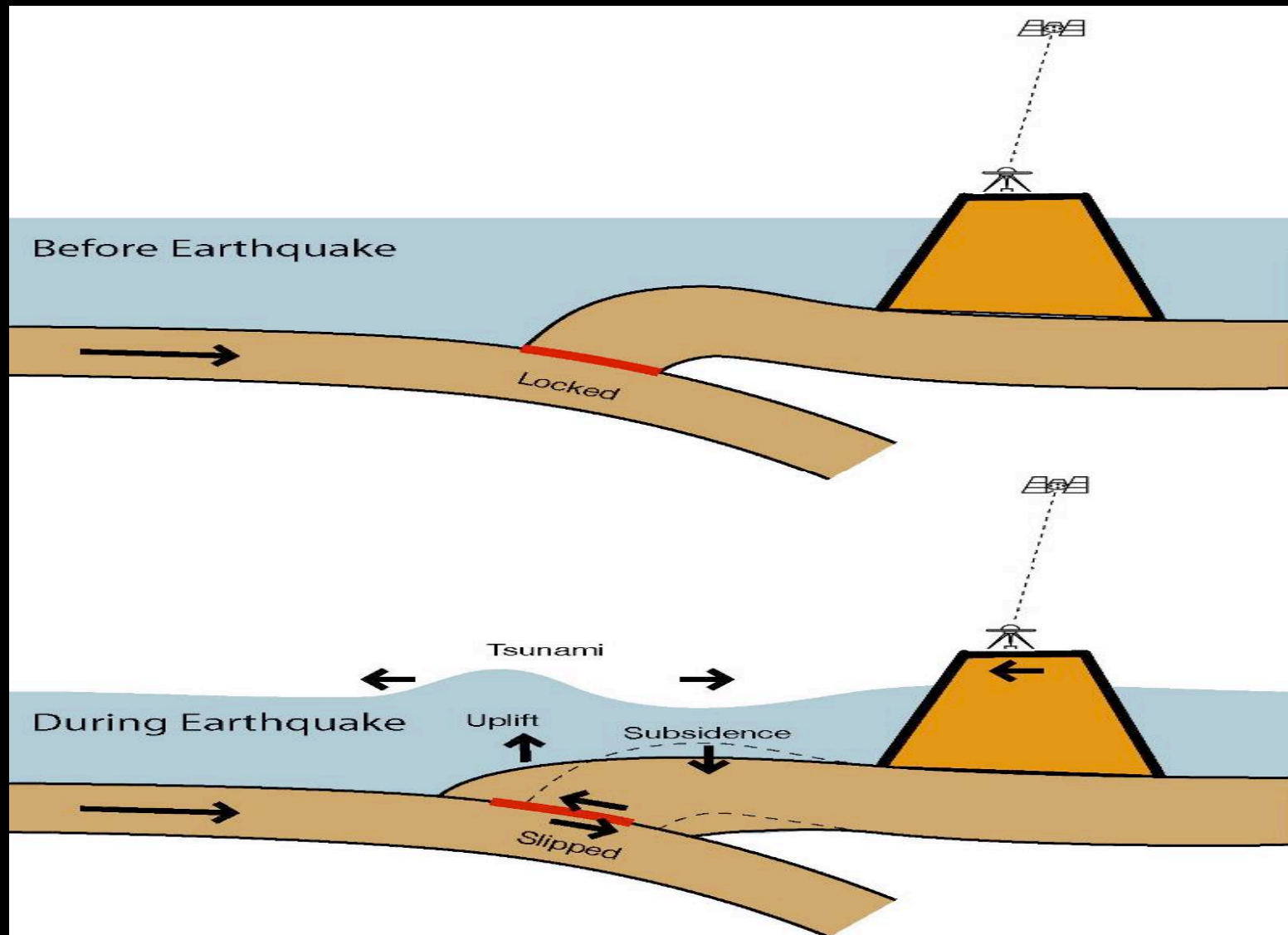
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PBO-Continuous GPS



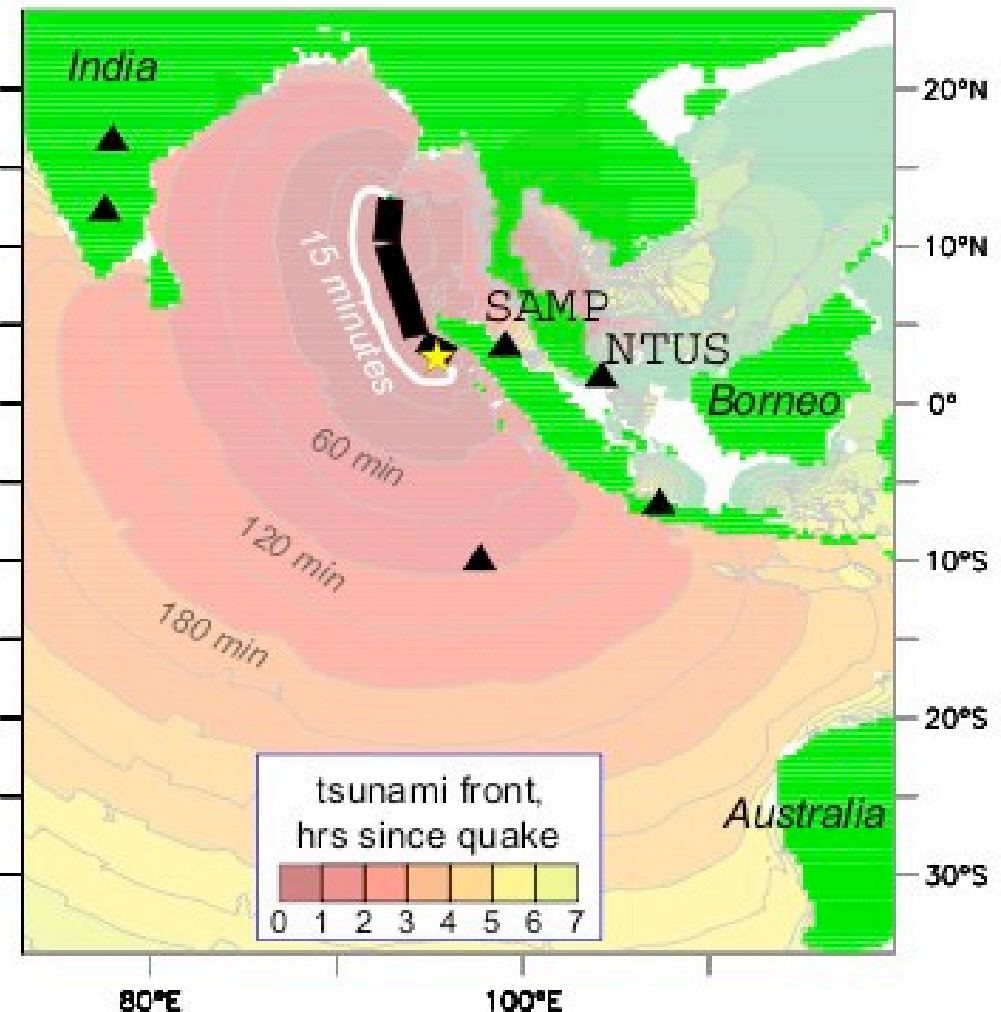
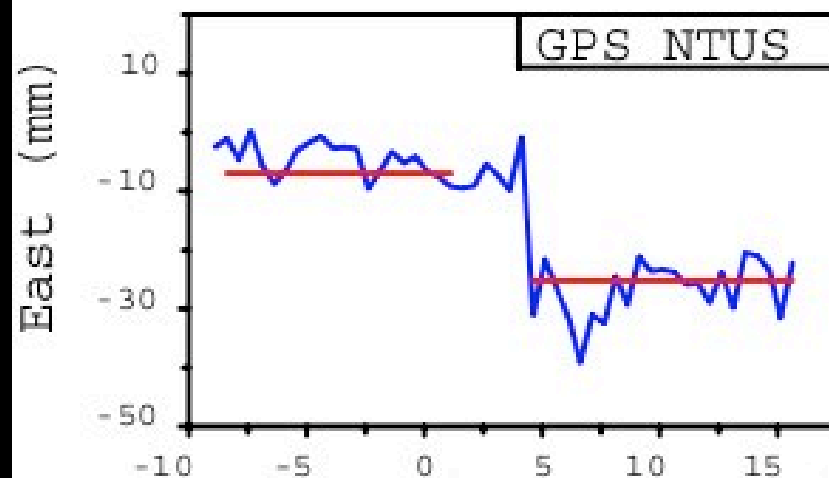
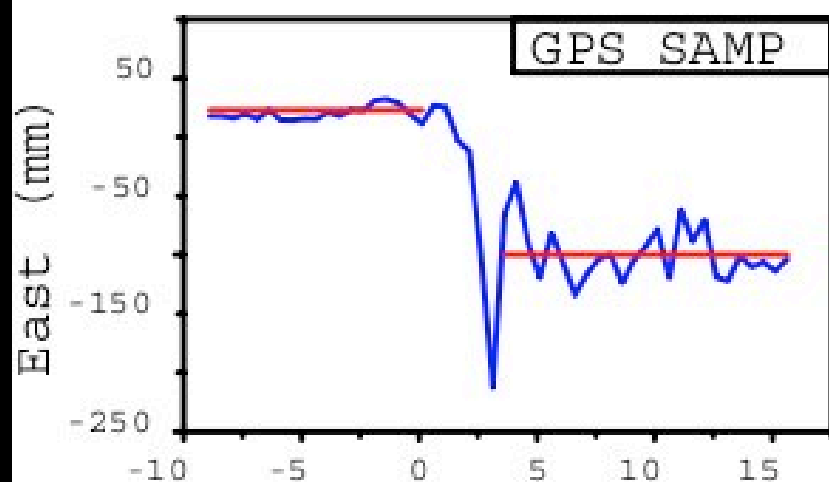
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GPS and tsunami genesis



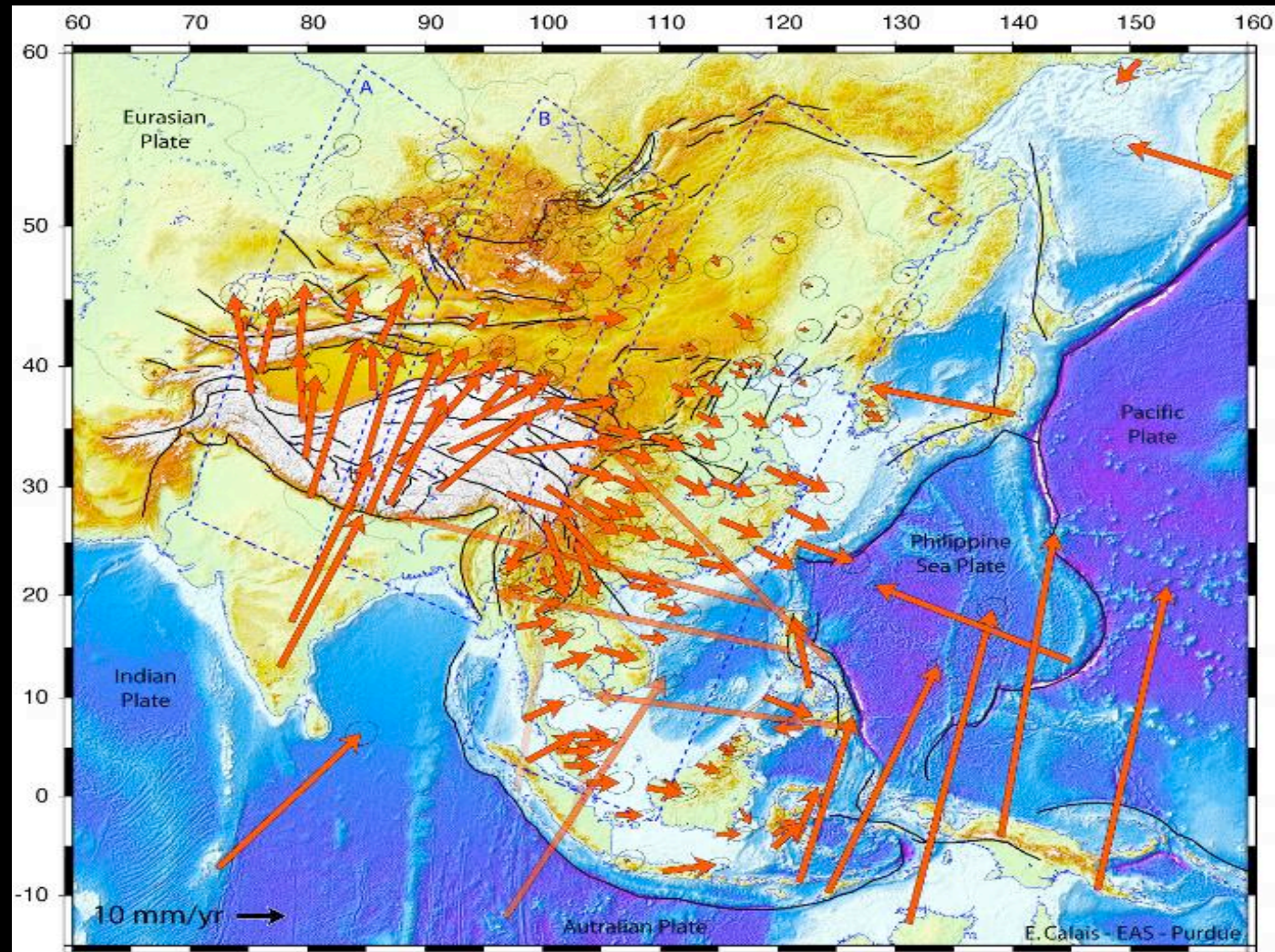
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Mw 9.2 Sumatra earthquake



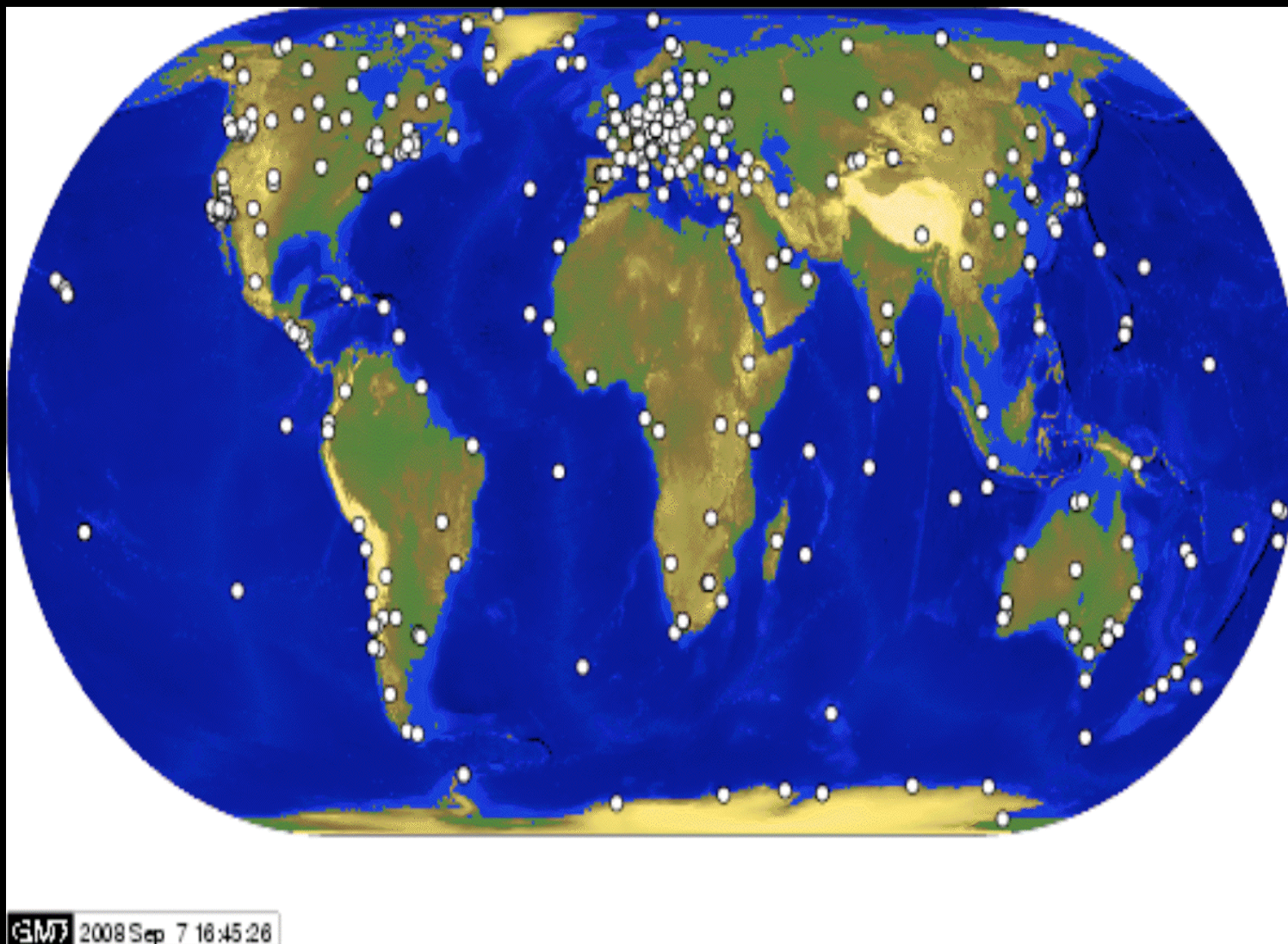
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Plate motion and deformation, GPS



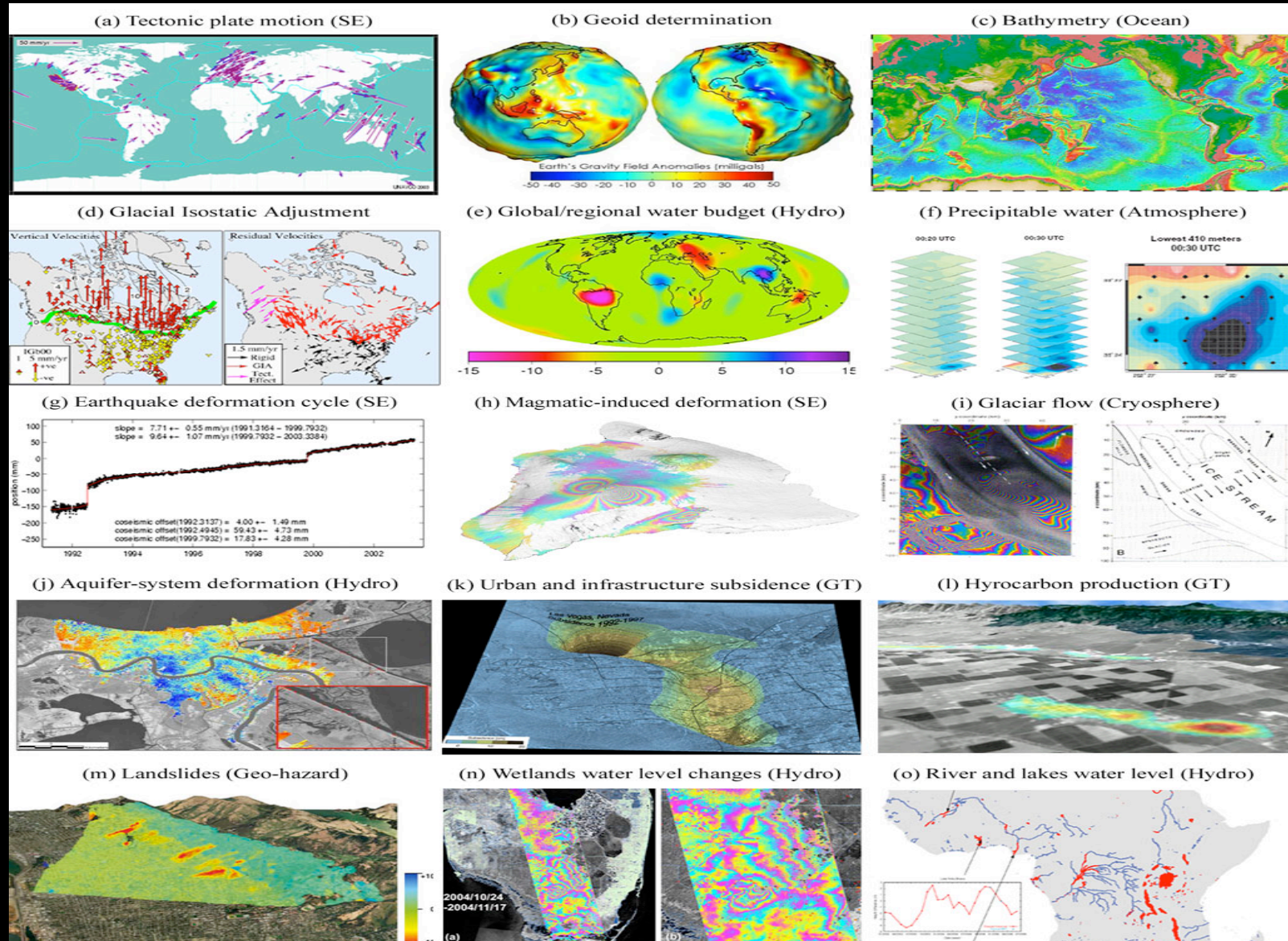
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IGS: 360 sites



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Space geodesy and Earth Science applications



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